the Petroleum Engineer

ds for Operating Men

JULY 1 • 1948

VOLUME XIX NUMBER 10

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Sept. 7-9—SAE, Tractor and Diesel Division, Schroeder Hotel, Milwaukee, Wis.
Sept. 9-11—Compressed Gas Mfrs Assn, Canadian Sec, Manor Richelieu, Murray Bay, Quebec, Canada.
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REFERENCE ANNUAL

DRILLING AND PRODUCTION

Economic Trends in Contract Drilling—*J. E. Warren* 51
Planning a Multiple Well Directional Drilling Program for Offshore Locations—*John G. Jackson and J. B. Murdoch, Jr.* 55
Offshore Drilling Development—*D. A. McGee, A. T. F. Seale, and G. O. Danielson* 65
Recent Diamond Coring in California—*William C. Harrington and Max C. Eastman* 84
Drilling Mud Problems of Rocky Mountain Region—*D. D. Varnell and W. B. Kimbrell* 92
Engineering Characteristics of the Gulf Coast Continental Shelf—*M. B. Willey* . . 97
Field Results of Jet Perforator Charges—*Robert Harcus* 107
Desirable Characteristics of Pumping Units and Engines—*J. C. Slonneger* 120
The Formation and Operation of Cooperative Projects in Secondary Recovery—*D. V. Carter* 126

REFINING AND NATURAL GASOLINE MANUFACTURE

Chemicals From Petroleum—*J. E. Bludworth* 146
Developments in Instrumentation in Analysis—*Ralph H. Muller* 156
Notes on the Initial Operation and Test Run of 100-Octane Aviation Gasoline Plant—*Utah Tsao* 161
Instrument Maintenance—*H. A. Hulsberg* 178
Gasoline Plant Process Water Treatment—*J. C. Hutcheson* 184

OIL AND GAS TRANSPORTATION

Automatic Controls in Gas Operations—*L. W. Parten* 189
Cooling Water for Gas Booster Stations—*A. V. Mueller* 202

GENERAL

Bibliography—Classified List of Important Papers Given During Preceding Year . . 208
Subject Classification 208
Author Classification 225
Organization Classification 252

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Irwin-Keasler Building, Dallas 1, Texas **Phone: Central-4571**

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PROMOTION—ABBOTT SPARKS, *promotion manager.*

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Articles in The Petroleum Engineer are indexed by Industrial Arts Index

A. B. C. SUBSCRIPTION: 1 year, $2 — 2 years, $3 A. B. P.

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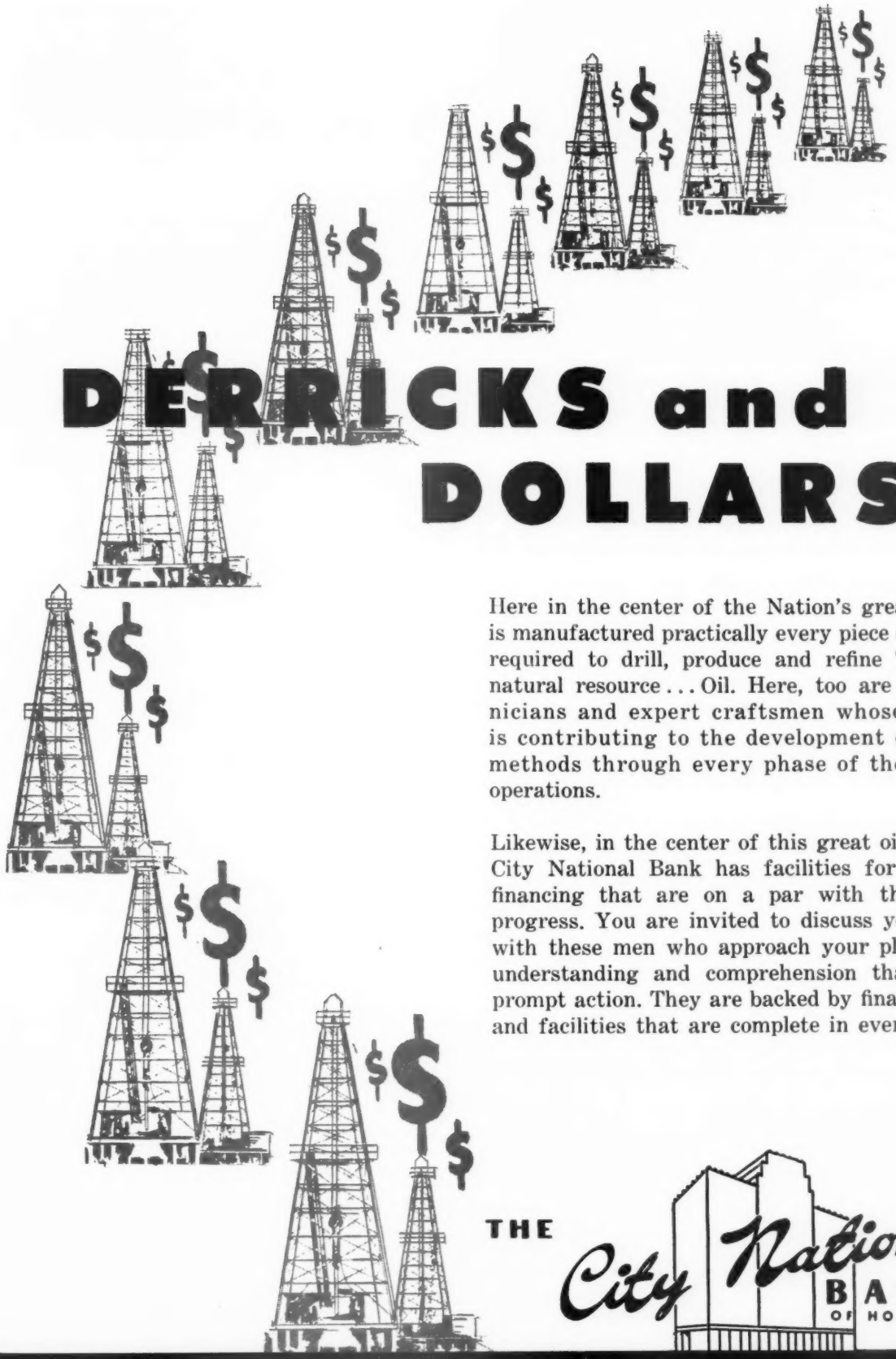

DERRICKS and DOLLARS

Here in the center of the Nation's great oil empire is manufactured practically every piece of equipment required to drill, produce and refine Texas' great natural resource . . . Oil. Here, too are skilled technicians and expert craftsmen whose knowledge is contributing to the development of improved methods through every phase of the Industry's operations.

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Editorial

If you ever make a list of reasons for the unique accomplishments of the U. S. oil and gas industry, don't leave out the importance of the literature. It isn't spectacular and hasn't any "best seller" appeal but it is a wide and deep foundation upon which the complicated structure of the petroleum industry can be built with safety.

Although the literature is voluminous today, it was virtually nonexistent forty years ago. Early operators borrowed from the empirical knowledge of salt and water well drillers and from the theories of engineers and geologists. Literature concerned specifically with petroleum is a 20th century product.

The pioneers who recorded ideas of oil and gas reservoir behavior and the results of operational methods laid the cornerstones of the industry's literature after the beginning of this century. Some of these foundation stones were later replaced but many still solidly support modern theories and practice.

In the highly specialized industry of today you cannot possibly read all the papers prepared for the huge network of organizations in the petroleum and affiliated industries. Bibliographies of articles and papers help to provide references to the newest thought in your own particular work without going through all the literature.

In recent years, however, the advance of new tools and techniques is such that information accumulates before regular channels can distribute it. Under these conditions the time gap between the publication of papers and their classification in available bibliographies is detrimental to steady progress.

One solution to this problem is the publication of an annual, up-to-the-last-meeting bibliography of most of the important papers pertaining to the industry released within the year. In this issue will be found a bibliography comprising the very latest material classified for easy reference. Its objective is to accelerate distribution of improved methods to experienced operators and to help initiate new graduates who have chosen to enter the oil industry.

The bibliography, which will henceforth be an integral part of the Reference Annual, is classified under: (1) Authors, (2) subject matter, and (3) organizations that sponsored the reports. The literature of the industry can thus be readily examined soon after it is published. A file of the annual bibliography will provide a permanent reference that will grow more valuable with each year's edition.

The Reference Annual is a special number, not one of the monthly issues, and therefore does not carry the regular features. The contents are selected papers of significance that have been presented during the previous year.

Economic trends in contract drilling*

By J. E. WARREN, Carl B. King Drilling Company

THOSE engaged in the petroleum industry can take pride in the remarkable progress that has been made in the science of discovery, efficient and conservative production, and the highly specialized techniques in refining oil. Similarly, those employed in the drilling business can be proud of the progress made in the art of drilling wells. Improved drilling practices and design of equipment with greater efficiency and increased capacity, together with increased proficiency of supervisors, engineers, drillers, and crews, are real and substantial contributions to the petroleum industry.

There are more rotary drilling rigs operating today, drilling a greater amount of footage, than at any other time in the history of the petroleum industry. Authorities concur in their beliefs that a high rate of drilling must be maintained in order to provide a sufficient number of wells to meet the nation's need for petroleum. In fact, the volume of steel tubular goods made available to the industry will control and limit the rate of drilling in the unforeseeable future. The need for more and more drilled wells makes it important that operators correctly appraise the trends and understand the basic fundamentals that affect the efficient and economic drilling of wells.

The art of drilling wells constitutes an important and specialized part of the oil business. Most drilling operations can be more effectively managed by independent contractors. Because they have greater independence of action, they can distribute their services to more than one company. They have specialized experience and knowledge, and they are ever vigilant and alert towards promoting economies because of the inducements of the profit incentives and the strongly competitive nature of the business. The high percentage of wells being drilled by independent drilling contractors is ample proof of the essential position that they now occupy in the industry. According to a recent and reliable survey, 82 per cent of the rotary rigs actually drilling holes are owned and operated by independent drilling contractors. The remaining 18 per cent of the total active rigs belong to oil companies, who operate them in drilling their own wells. Approximately 500 contracting firms that are stable in character are engaged in the rotary drilling business. They range in size from one rig owners to drilling companies who operate businesses worth several million dollars.

It is axiomatic that oil companies employ contractors only because they believe that greater benefits will result, when all factors are considered, than if they drilled all their wells with company owned and operated tools. The money paid for drilling wells must ultimately come from oil produced and marketed to the public and the industry eventually absorbs any of the mistakes and inefficiencies that may result from drilling operations, and likewise receives the benefits that accrue from the employment of new and more efficient methods and equipment.

Drilling contractors must, in order to continue holding an important place in the petroleum industry, render a valuable and progressive service. To assure that maximum benefits will result from the services of drilling contractors it is important that underlying principles and trends affecting the contractor's business and factors concerning the company-contractor relationship be fully understood.

What are the trends and basic elements in the drilling business that have a bearing on the cost of drilling wells in the future? Properly to understand and discuss this question it is desirable to consider the problem from two points of view. First, the specific trends that are the result of a combination of specific factors such as prices, costs and efficiency. Second, the general trends that are dependent partly on the general course of the oil industry but are also influenced to a large extent by changes and circumstances within the drilling business itself. Let us look into the specific trends that influence the drilling business today.

● **Specific trends.** Although the fundamental operations employed in drilling wells are the same everywhere, they vary

*Presented before 27th Annual Meeting, American Petroleum Institute, Chicago, Illinois, November 11, 1947.

FIG. 1. Percentage analysis of drilling costs.

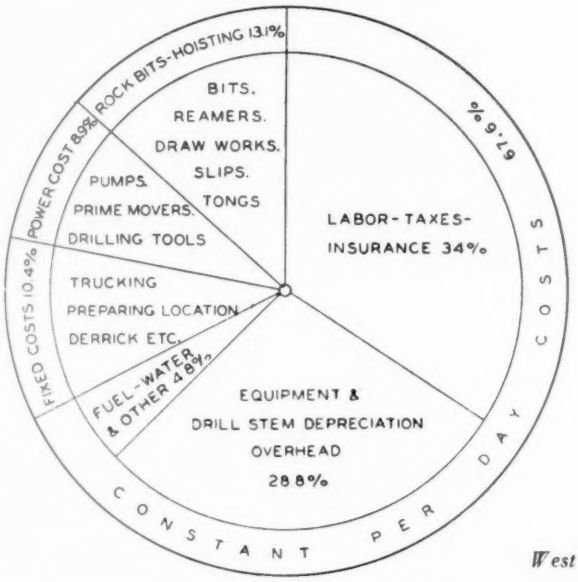
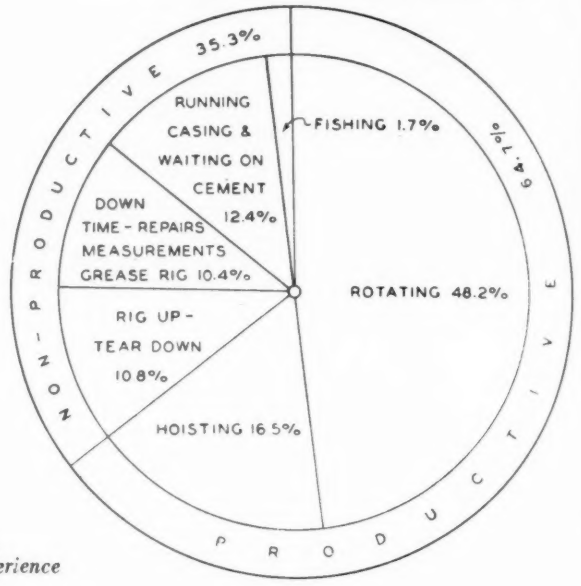


FIG. 2. Percentage analysis of drilling time.



Based on West Texas experience 1947

in relative importance, depending on the difference in conditions that exist between locations, formations, and drilling depths. The analysis of statistical data concerning drilling operations, as in all complex practices, must be adjudged and valued on the basis of experience and intimate knowledge of the controlling conditions. The examples used are based on experiences in drilling West Texas wells but the conclusions are of general application provided power values are given to the variables involved.

● **Evaluation of operational factors.** In order properly to evaluate the various factors, it is essential that the major operations be analyzed from the standpoint of cost and time required for each one.

Fig. 1 illustrates the relative importance of costs involving depreciation, overhead, and labor, which are directly proportional to the elapsed time on a given operation. It also shows those costs that are fixed regardless of the drilling time and those cost that are partly based on time and partly due to intensity of service.

Fig. 2 shows the percentage of total time employed in actual drilling operations compared to the time consumed in preparing to drill and performing other essential operations.

These charts are shown in order that the observer can consider and appreciate the relative importance of each functional operation in the drilling of wells, from the standpoint of both cost and time.

● **The cost factor.** Rotary drilling equipment, labor, and materials have substantially increased in cost in the last few years. A rotary drilling rig, complete with drill pipe of sufficient capacity to efficiently drill wells deeper than 9000 ft in West Texas that cost $217,000 in 1943, has increased in price to $284,000 today. This represents an increase of 31.2 per cent in the weighted average price of capital equipment used in rotary drilling operations. In order to attain the maximum efficiency gained through improved methods, an additional $40,000

FIG. 3. Increase of operating costs due to increases in prices, labor, material, etc. Typical 1944 well costs expanded to 1947 costs.

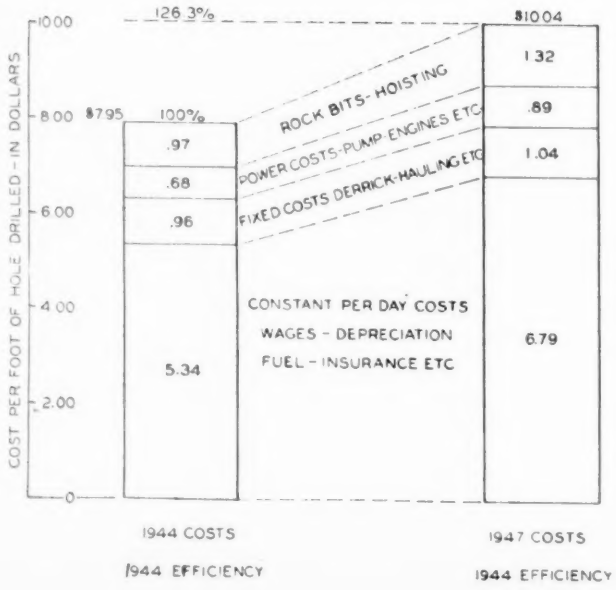
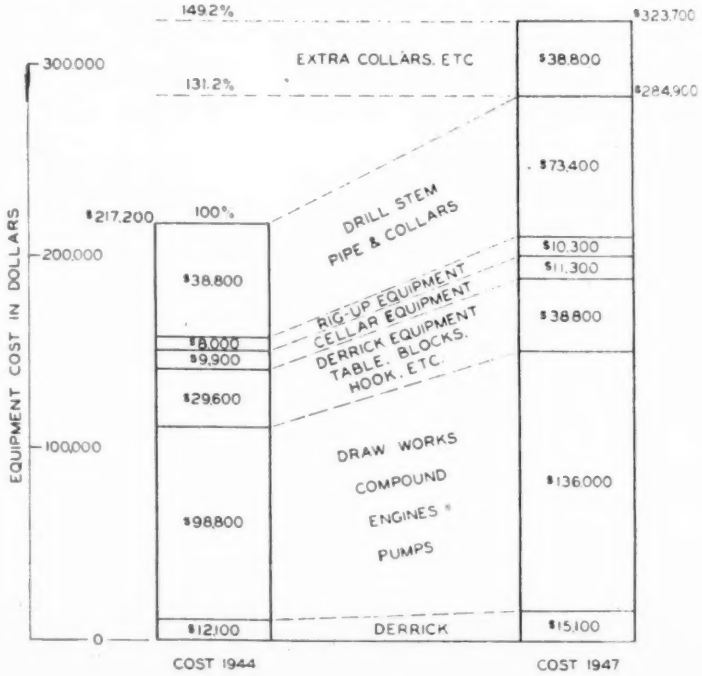


FIG. 4. Comparison of capital investment heavy West Texas rig.



in drill collars and equipment would be added to the cost of this typical rig, making the total cost $324,000 if purchased today. In addition to the 31.2 per cent average increase in price, there is an increase of 18.1 per cent to gain added efficiency, making the total increase 49.3 per cent. These increases are graphically illustrated in Fig. 3.

The cost of all items of expense have increased proportionately. Fig. 4 shows the cost of a typical well in 1944 expanded to what this same well would cost today. These figures are based on 1944 experience and do not allow for increased efficiencies developed since that time.

The trend in costs is still rising, and is common to all areas of development and types of drilling operations.

● **Increased efficiency.** The average rotary drilling rig in the United States is drilling approximately 25 per cent more hole per day now than it was at the start of the war-time demand for drilling and 20 per cent more than in 1945 when rotary drilling was at its war-time peak. Part of this increase can be directly attributed to the return of experienced and efficient workmen from the war and the remainder to the employment of efficient equipment and development of improved drilling methods. Drilling equipment throughout the industry is more up-to-date, more efficient, and better maintained than at any other previous period in the history of the drilling business.

● **The time factor.** Many of the costs necessary to drilling wells are directly related to the length of time required to complete the operation. The time factor is so important that erroneous comparisons are often made on the basis that the overall costs of drilling are directly proportional to drilling time.

Those engaged in the drilling business are constantly analyzing their operations and altering drilling procedures in an effort to reduce the number of days required for drilling wells. The primary purpose of drilling is to "make hole" and hole is only "made" efficiently when the bit is on bottom a maximum amount of time, drilling at its most productive rate.

● **Cost per operating day.** It is impossible for a contractor to make an intelligent bid on drilling certain types of formations because of unpredictable variations in drilling characteristics and in some instances because of unusual hazards. The practice is to pay a specified daywork rate to contractors for services performed under these conditions. Daywork rates are also paid for testing, coring, electrical surveys, etc. As daywork constitutes an important item in drilling wells, it is advisable to show the elements of cost involved in this type work.

Fig. 5 shows the relation of cost per day compared to the number of drilling days for a given set of conditions. The trend of operating costs per day compared to the number of drilling days per well are clearly shown. Cost per day versus days per well are illustrated in two ways. First, the cost trend if all prices of materials, labor, equipment, etc., were stabilized at the current level.

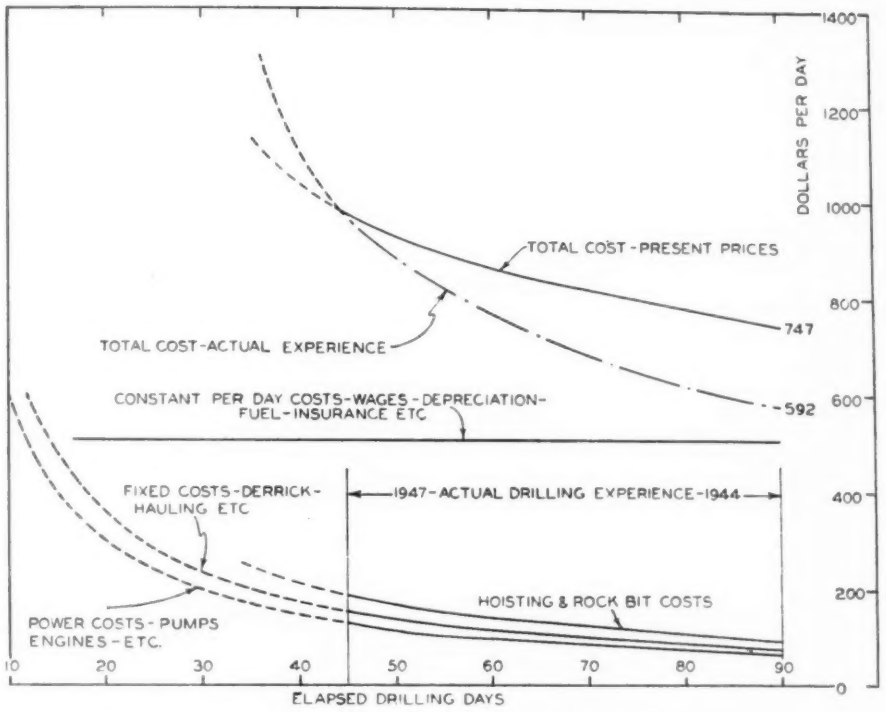


FIG. 5. Relation of cost per day to total drilling time.

Based on experience wells drilled during 1944 to 1947
Average depth 6700 ft, West Texas

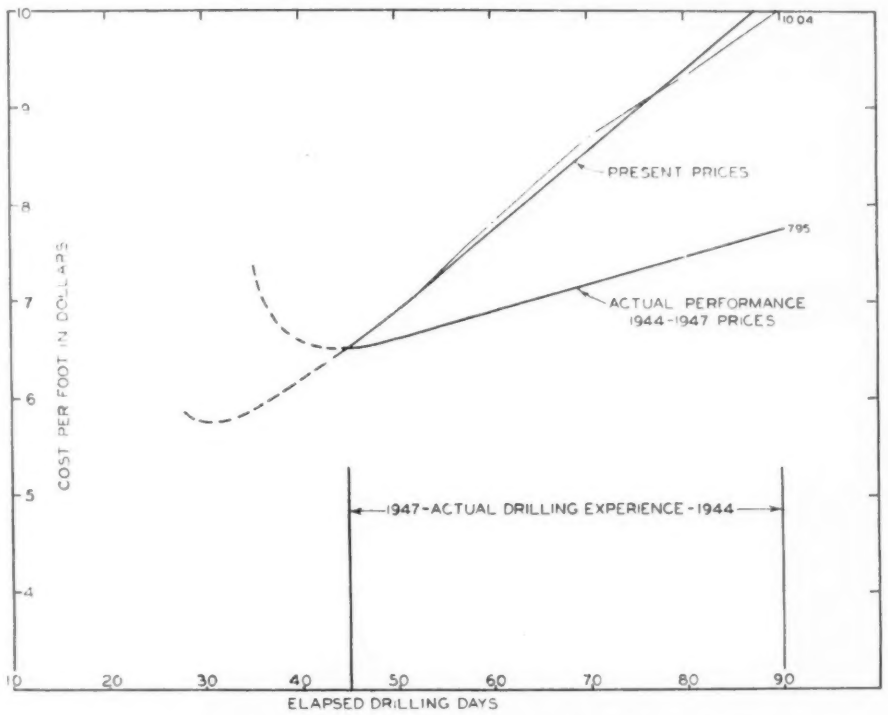


FIG. 6. Relation of cost per foot to total drilling time.

Based on experience wells drilled during 1944 to 1947
Average depth 6700 ft, West Texas

Second, the cost trend as it has actually developed since 1944, including the increase in prices of materials, etc., that have occurred since that time.

It can be seen that the cost per day increases more rapidly as fewer and fewer days are required for drilling wells. This is an important point in considering daywork rates as it puts a premium on inefficiency and a penalty on outstanding performance. Daywork rates should be devised to offer an incentive for increased efficiency.

● **Cost per foot.** The cost per foot is of permanent importance as it is directly related to the revenue received by the

contractor and represents the cost to the company for drilling services.

Fig. 6 shows the cost per foot of hole drilled using the information developed in Fig. 4 and using 6700 ft as the average depth of the wells considered.

It can be readily seen that an increase in efficiency resulting in fewer drilling days has a decided bearing on the cost per foot of hole drilled. The relationship between drilling days and cost per foot is not constant and there is a point where further reduction in drilling time will not result in reducing the cost per foot. This condition can only be altered by a fundamental improvement in drilling methods.

● **General trends.** The historical trend of the drilling business has been cyclic in character. A cycle begins with a period of acquisition and progress and ends with a period of liquidation and stagnation.

The large investments that are necessary to drill wells today must be amortized over several years. They are only possible when there is an incentive of unusual profits or the prospect of lasting stability in the business. The drilling business has been characteristically unstable throughout its history and it is the incentive of unusual profits that periodically attracts capital into the drilling contracting business.

When the demand for drilling wells exceeds the available supply of efficient drilling equipment, sufficient profit incentives are developed to attract new and additional capital into the business. During this period of high profits, acquisitions of new and efficient equipment are made, better equipment designed, and improved drilling methods are practiced. The increased efficiency resulting from improved equipment and methods progresses until the business is in a state of over-expansion. This over-supply of drilling rigs marks the beginning of a period of liquidation and stagnation.

When drilling rigs are in oversupply, intense competition results and drilling prices are reduced to a minimum. Wells are then drilled at or below the margins necessary for depreciation and overhead. The inevitable result is liquidation of physical assets into cash, and equipment becomes obsolete and worn out. We have experienced two complete cycles of this character in the last 20 years, and are now in the middle point of the third one. To illustrate these cycles, Fig. 7 was prepared showing the number of wells completed, and the total demand for oil in the United States by years. Periods of acquisition and progress occurred from 1926 through 1929, from 1934 through 1937 and from July 1943 through 1946; these periods are cross hatched on the chart. Periods of liquidation and stagnation occurred from 1930 through 1933, from 1938 through June, 1943, and the last part of 1947. The length of each period is approximately four years, and the complete cycle about eight years.

The current cycle began when the war demand for drilling started in the middle of 1943. The drilling industry was at that time in a depleted condition in both personnel and equipment. Drilling was held at a minimum in 1942, and the first half of 1943, and experienced drillers and roughnecks were attracted to the war industries, or into the armed services. It was, therefore, necessary to create profit incentives that would make it possible for contractors to operate with inefficient and inexperienced labor, and rehabilitate and purchase modern and efficient equipment.

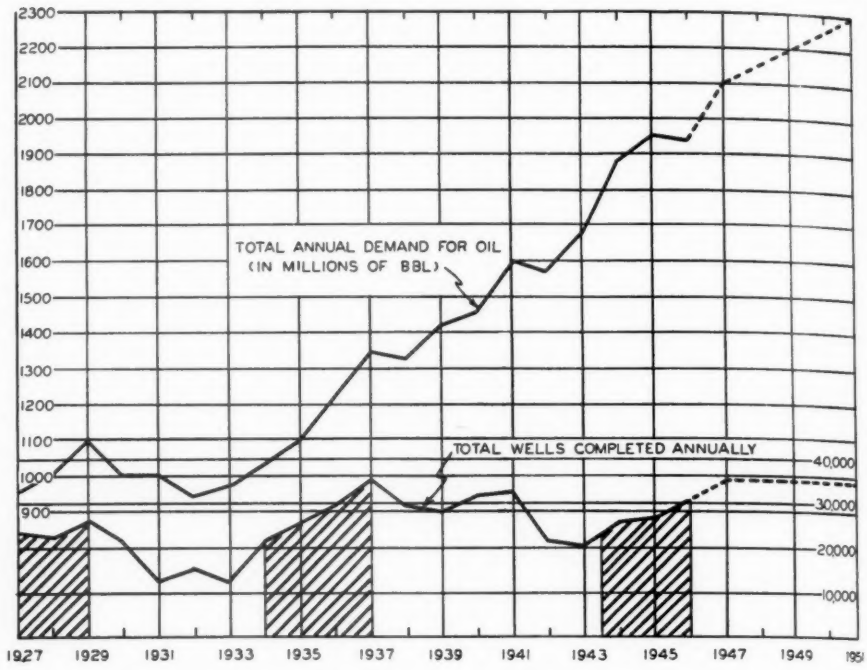


FIG. 7. Total demand for oil and total wells completed in the United States by years.

New drilling rigs were purchased and improvements in drilling methods continued to develop until 1946. The supply of drilling rigs again exceeded the industry's demand for drilled wells and the resulting competition between contractors forced a sharp reduction in the price of drilling. The return of efficient and experienced workmen to the drilling business and the employment of modern equipment and improved methods resulted in reducing drilling costs sufficiently to compensate for the reduction in drilling prices. The increased costs of equipment, materials, and labor are now exceeding the savings made in operating costs realized through increased efficiency.

● **Conclusions.** The excessive fluctuations that make up the typical drilling business cycle are uneconomic and expensive to the petroleum industry. The price of the periodic rehabilitation of the drilling industry and the real but intangible losses that occur during periods of liquidation are substantial. Anything accomplished that will lend a measure of stability but maintain healthy and progressive competition will be a real and economic gain to the petroleum industry as a whole. Oil companies strive to reduce their drilling costs to a minimum which is a natural consequence of good business management.

Immediate gains, however, that are obtained by the reduction of drilling prices below costs will be wiped out by future losses that this uneconomic condition will create.

Oil companies and drilling contractors alike will receive maximum benefit from their business relations if the basic economics of contract drilling are studied and evaluated realistically.

Reviewing the trends that are now developing in the drilling business, we reach the following conclusions:

1. The limiting factor created by an insufficient supply of oil country tubular goods does and will continue to control the rate at which wells will be drilled in the unpredictable future. This condition creates a ceiling on the rate of drilling at a level where drilling rigs are in competitive supply.

2. The costs of labor, material and capital equipment have increased tremendously, and at the same time revenue from drilling has dropped to a point at which many contractors are again operating on depreciation and overhead margins.

3. If these conditions continue the efficient state of the drilling business that now exists will deteriorate and unusual profit incentives will again be necessary to attract needed capital and drilling prices will rise accordingly.

It behooves company and contractor alike to give serious consideration to the present state of the drilling business. The current rate of drilling is going forward at a cost to the petroleum industry of roughly $500,000,000 per year. This cost must be continued into the unpredictable future if the industry's need for drilled wells is met. It is therefore important that the drilling industry maintain a high level of efficiency and that each problem and condition that affects efficiency be recognized and met in a realistic manner. ★ ★ ★

Planning a multiple well directional drilling program for offshore locations*

By JOHN G. JACKSON† and J. B. MURDOCH, JR.‡

● **Introduction.** A petroleum engineer must consider many and varied factors when planning a long range directional drilling program for an offshore or inaccessible location on an oil structure. The basic principles of directional drilling planning and operation must be reconciled with his company's drilling practices, and frequently special concessions to standard drilling and production practices should be made. The field techniques and tools used in directional drilling are well known and widely used, but the deliberate, careful planning of a complete directional program is in the main a recent innovation. This development, plus the increased demand for oil resources and the consequent exploitation of inaccessible structures and offshore locations, has placed this problem before many engineering departments for the first time.

Directional drilling programs of a very complex and difficult nature have been successfully carried out in the Mid-Continent and Pacific Coast regions. The planning itself of a directional drilling project, however, has not had the careful analysis it deserves and we can reasonably expect widespread future progress along these lines. Data and experience gained in these programs by the directional drilling service companies and the oil producers have been studied with the objective of giving the engineer a better conception of the factors that govern the various steps in planning a series of directional wells. The newest engineering procedures are the result of recent careful analysis of years of directional drilling work accomplished under the supervision of directional drilling service companies working with the oil companies.

The purpose of this paper is to illustrate the mechanics in planning a complete directional program on an oil structure where the productive limits are known. This will be done by means of an example of procedure. Before giving the example, a number of factors will be listed and discussed that would affect the particular problem so that the engineer will have a better conception of the steps involved in working up a logical plan. The authors are aware that other ways of directional drilling planning exist and wish only to submit this as a typical example for a particular project and not as an attempt to cover the general field of directional drilling applications.

*Presented before Petroleum Division, American Institute of Mining and Metallurgical Engineers, at Tulsa, Oklahoma, October 8-10, and at Los Angeles, California, October 23-24, 1947.

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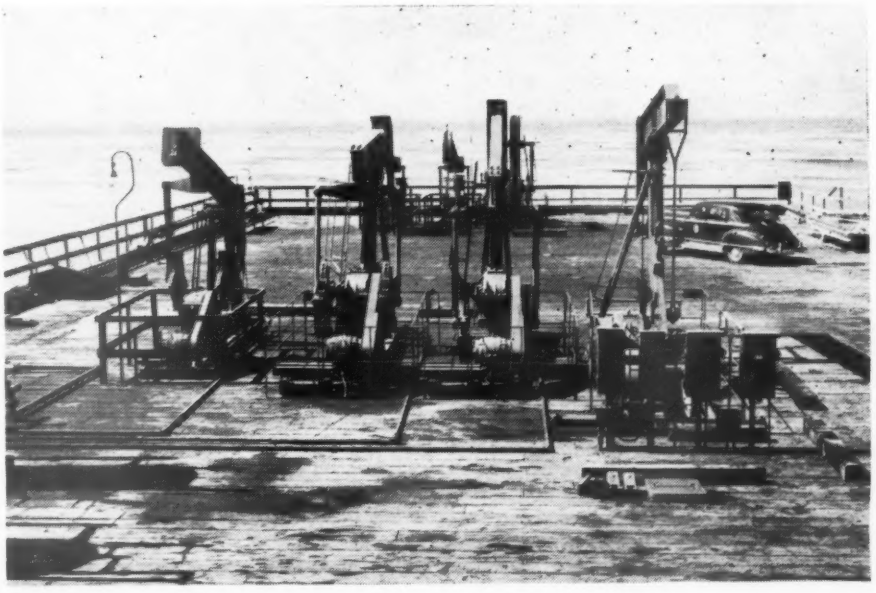
● **Geological factors affecting directional programs.** The choice of a suitable proposal for a series of directionally drilled wells is affected by the geological conditions found in the area where the work is to be carried out. From the economic viewpoint the engineer must have an idea of the productivity of the formation that is to be penetrated by the directed well. For instance, the rate of production in a slant hole sometimes is larger than in a straight hole because of the greater area of oil sand exposed. Well spacing laws and regulations controlling bottom hole spacing may also interfere with what may be an ideal program. If the engineer does not have data that can be used on such problems as that of expected production rates he is at a disadvantage in trying to estimate costs and the economics of the program.

Directional wells must be planned to take advantage of multiple zone completions, possible further deepening to lower zones, or the further perforating of a higher oil horizon. Under the last three conditions spacing is one of the most important factors and the proposal should be drawn so that each well can be used to the maximum benefit. Ordinarily the directional wells in a program are not all drilled at the same angle, so that unless the proper type of well proposal is chosen, the spacing is correct for only one zone. This factor is frequently overlooked and has resulted in the drilling of extra wells that careful planning would have made unnecessary.

The location of the artificial island so that the wells may be most advantageously drilled is influenced by the type and depth of the oil structure. The starting point of the wells should be located so that when they reach the productive zone the drift angle will be the proper one at which to penetrate the oil sands. Dip of the formation and the type of the oil structure also have a definite relationship to the proper drift angle of the well. A change in the drift angle or direction of the well will many times radically affect gas-oil ratios, rate of production, ultimate production, etc. When geological conditions are such that a directional well must penetrate a number of oil zones all lying close to a salt dome, the proposal can be drawn so that the well will penetrate the zones parallel to the side of the salt dome. This can be accomplished by allowing the well to become vertical before entering the first zone or by directing the well's course in a plane parallel to the side of the salt dome. This last system permits the penetration of many oil horizons at points equi-distant from the face of the salt dome without the necessity of changing the drift in the directed well. This same problem arises in drilling highly faulted zones and is successfully solved in the same manner. The dip and strike of the formation, as well as its physical proper-

FIG. 1. Pumping equipment installations showing surface spacing in a 7-well directional program on a Pacific Coast pier location.



ties affect the drilling of the directional well. Under ordinary circumstances the wells that are drilled in a direction normal to the strike will be the easiest to control, while those that are parallel to the strike will cause the greatest difficulty.

In exploring a probable oil structure with the bit, a directionally drilled hole can be used to advantage. A high angled hole that has been drilled to the supposed productive horizon and that has failed to encounter oil sand may be plugged back to a shallower depth. From this plug the well is redrilled straight to explore nearer the surface location. On one deep, high angled well, three separate bottom hole locations were explored by successively plugging and straightening the well; thus the upper hole served for three test wells resulting in a considerable saving to the drilling company.

● **Selection of maximum drift angle and starting point.** The proper point from which to start the deflection of a directional well depends upon the formation characteristics, the average drift angle selected, and the rate of increasing this drift angle. The rate of increasing drift angle and the maximum drift angle are governed also by the total vertical depth to the oil sand and the horizontal deflection desired. These factors vary considerably with each field development; however, the engineer can follow certain basic considerations in his planning.

In general, the well proposal should be laid out so that the build-up rate and drift angle will be feasible. An average figure for the rate of building drift that is used in many instances is 2½° to 3° per 100 ft of hole drilled. There will be cases, however, where a high drift angle has to be obtained quickly, and many directional drilling programs have called for an increase in the drift angle of as much as 6° to 8° per 100 ft until a maximum drift angle of from 60° to 80° from the vertical has been achieved. The measured depth of such a high angle well of this type will rarely be greater than 8000 ft. In all cases where conditions permit, however, the best practice is to increase the angle slowly and drill a little more directional hole to get to the objective.

The average drift angle of the directional portion of the well is an important economic consideration in planning. Too low a drift angle or unnecessarily high angles are not recommended. Drift angles of 15° to 45° are successfully maintained for thousands of feet, and it is in this range that the most economical directional drilling is accomplished. Very low angles definitely increase the cost because of the greater amount of directional hole which has to be drilled and the difficulty of controlling a low angle hole while drilling. Very high angle wells also present special difficulties in logging, surveying, and running casing.

The point or depth at which the deflection work is started will materially affect the directional program and the overall cost of the job. By the use of a

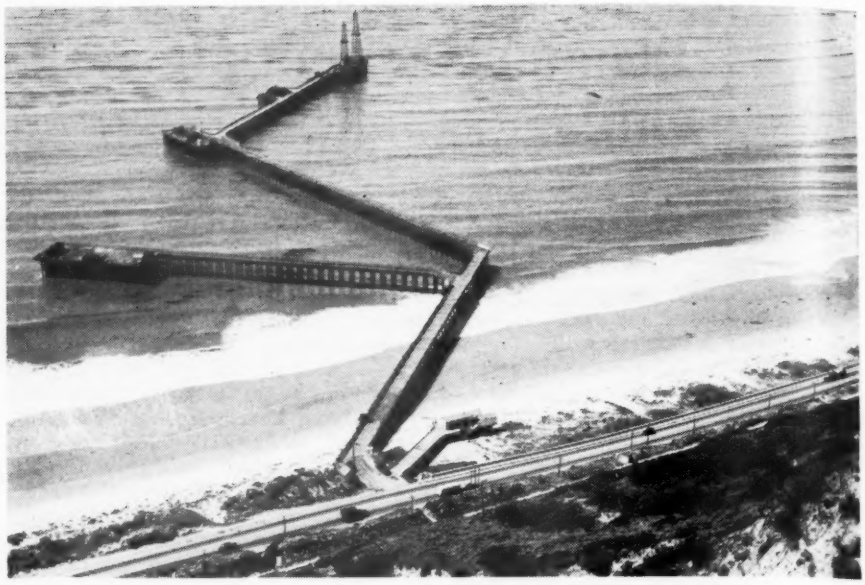


FIG. 2. Aerial view of pier construction from which a directional drilling program has been completed successfully. A close-up of one of the pier-head locations is illustrated in Fig. 1.

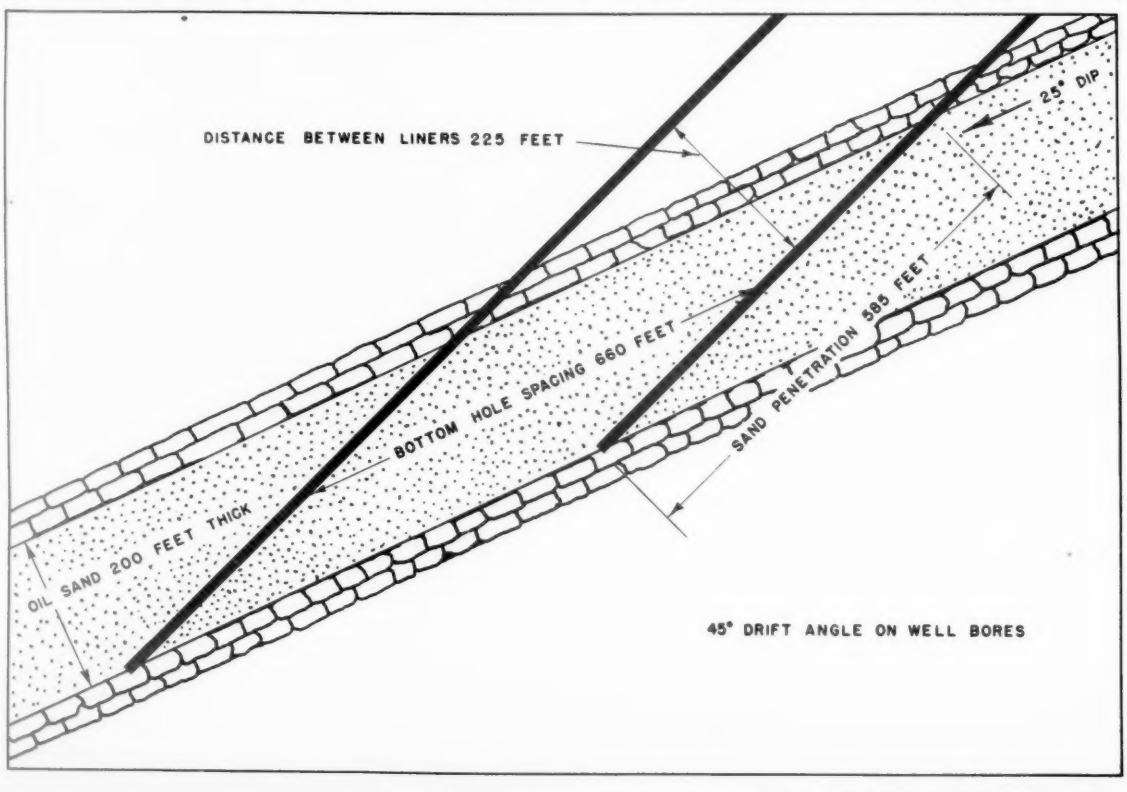

DISTANCE BETWEEN LINERS 225 FEET
25° DIP
BOTTOM HOLE SPACING 660 FEET
SAND PENETRATION 585 FEET
OIL SAND 200 FEET THICK
45° DRIFT ANGLE ON WELL BORES

FIG. 3. Section showing bottom-hole spacing in oil sands of two high angled wells. Well spacing is on mid-point of sand thickness.

reasonably high angle in the directed portion of the well, the directional work can be started deeper and more straight hole may first be drilled. When this is possible it will generally result in saving in rig time and other costs. Also, when the well is on production the possibilities of mechanical difficulties are less when the directional portion of the bore is near the bottom.

The problem of surface spacing and clearance of wells is related to the starting point and is discussed in the next section. The starting point, the depth, the desired deflection, and the average drift angle which are chosen all bear a definite relationship to one another which must be analyzed.

The formations that are to be drilled should be studied, and the rate of penetration determined, so that the best zone in which to do directional drilling work may be selected. The well should definitely be planned so that directional drilling tools will in all probability not have to be set in unsuitable zones.

● **Well spacing and clearances.** Theoretically it is possible to drill a large number of wells from one site; practical considerations, however, materially reduce this theoretical number. The spacing of wells on an artificial structure must be made with due consideration to the difficulties that may arise during the drilling period and the productive life of the well. In high pressure fields, very close spacing could, in case of a blowout or fire, unnecessarily endanger a great number of wells. Also, space should be left for future pumping and servicing operations after the wells stop flowing. The photograph, Fig. 1, illustrates a typical well spacing plan on a pier head in the Pacific Ocean where the wells are being pumped.

There has been a great deal of experimentation on the problem of surface spacing and the following discussion is based upon a study of many types of spacing plans. Each directional program may call for a special spacing and arranging plan governed by factors characteristic of the production and drilling conditions.

There are two very distinct types of island plans for directionally drilled wells. The first and easiest plan to lay out pertains to an island where the wells radiate as do the spokes in a wheel. In this type the wells progress away from each other and the danger of interference between wells is at a minimum. The most common type, however, is the one in which all of the wells are drilled in substantially the same direction away from the unitized location. This type of island has to be planned very carefully in order that the great number of wells can be drilled without undue interference. Difficulties in the drilling operation are certain to occur unless the wells are laid out and drilled in a logical and systematic manner.

There are two general ways in which directional wells may be drilled so that interference is kept at a minimum. The first is to start the directional operations at different depths so that the wells will be separated shortly after they leave the island area. The second system is to have the wells build up to their maximum drift at different rates. The more distant wells would, under this last scheme, have the highest rate of increase in drift. In the case of high angle drilling in very congested areas both methods can be used concurrently in order to obtain sufficient clearances between wells.

Experience has shown that when directional work is started at very shallow depths of from 300 to 1000 ft, the surface locations may be made as close together as from 2 to 6 ft. When directional work is started at greater depths, the locations at the surface must be farther apart. This precaution is taken because in any survey the cumulative error is somewhat proportional to the length and number of stations. Some programs have called for wells passing each other as close as 3 ft at depths of 1000 ft or more, but this practice is hazardous and should be avoided if possible. If, however, a well has to pass near to another well, the proposal should be plotted so that the well passes under the one already drilled. Wells should never pass closely over other wells because of the danger of the pipe cutting downward into the casing of the producing well.

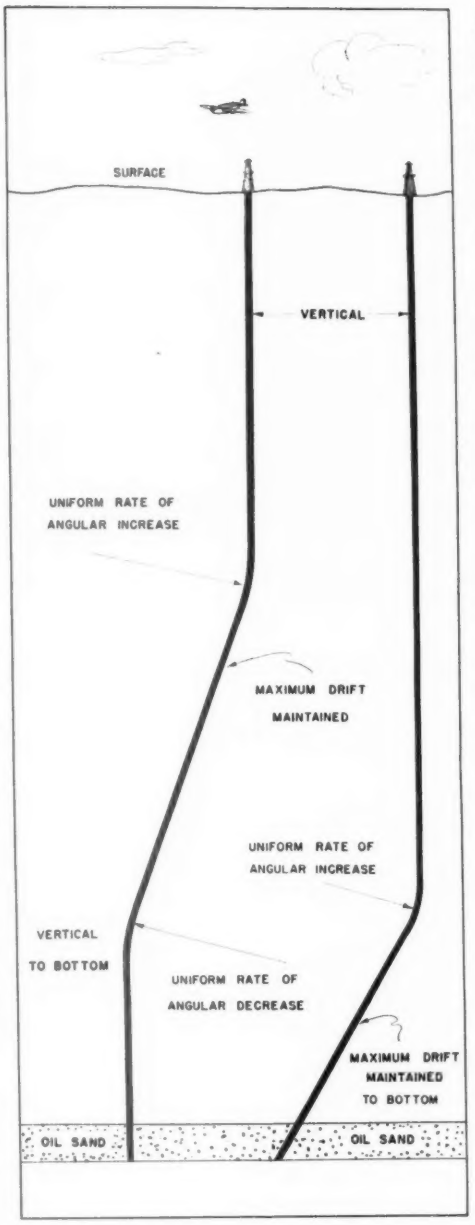


FIG. 4. Section illustrating two general types of directional wells.

The relationship of the surface spacing, the bottom-hole spacing, and well clearance must be taken into account when laying out a multi-well program. The vertical distance between wells which are deflected at high angles will in most cases be less than the horizontal projection of the bottom hole spacing in the oil zone. The bottom hole spacing is generally measured in a plane which is at the mid-point of the production zone.

These relationships are illustrated in Fig. 3, a sectional view, which also shows the increase in penetration of the oil zone by the use of slant wells. The bottom hole spacing is given as 660 ft and the distance between the well bores in this example is only 225 ft. The thickness of the oil zone is 200 ft but due to the angle and direction of the wells the penetration has been increased to 585 ft.

● **Engineering control and well proposals.** A directionally drilled well is not a "crooked" hole but is a directed well wherein all bends are controlled to stay within known safe limits. The most frequent causes of mechanical trouble in slant wells are excessive dog legs and unnecessary wandering of the course of the well. A "dog leg" is the term applied to a change in the course of a well. It may be either a change in drift or a change in direction or a combination of both. The amount or size of the dog leg can best be calculated graphically and is generally expressed in degrees as a total dog leg in a certain specific length of well bore.

By the use of new and improved deflection tools excessive dog legs or changes in the course of the well can be minimized. In general each formation will have its own particular tendency toward keyseating if the dog leg exceeds a certain maximum amount. Other factors such as time, drilling procedure, depth, and the mechanical condition of the well also contribute to the tendency of the formation to keyseat. In general, however, the controlling factors are the weight on the drill pipe which provides the force, the radius of curvature of the well, and the type formation. As it would not be practical to determine the maximum permissible dog leg for each formation, a safe maximum angle is chosen that will fit the requirements for efficient drilling and the requirements for later production practices.

The recommended practice, now widely used, is to limit the maximum increase in drift to 2°30′ to 3°00′ per 100 ft drilled and to limit the maximum "dog legs" caused by deflection tools to 3° in any 50-ft section and 5° in any 100-ft section of well bore. The overall proposal will be on a basis of a 2°30′ increase in drift per 100 ft drilled, and the direc-

tional driller will attempt to stay as close as possible to the outlined proposal. An example is shown in Fig. 10.

Directional wells are of two general types. In one the drift angle is increased at a uniform rate to the desired maximum deflection angle which is maintained until the oil zone is reached; in the second type the angle is increased at a uniform rate and maintained until the desired deflection is obtained at which point the well is brought back to vertical. Thus it passes vertically through the oil zone. These two types are illustrated in Fig. 4. The first method is the simplest and is the most widely used. The second system is used in situations where deeper horizons are to be explored or where directional drilling operations are difficult at the deeper depths.

A directional drilling proposal is drawn so that it illustrates both the course of the well and the cylindrical limits within which the well must be drilled. An important benefit to be derived from the use of cylinder drilling is that it guarantees a better well mechanically and definitely places a control on the quality of the field work. The field engineer can project the course of the well ahead of the drill and can thus judge exactly when to run a deflection tool and still stay within the maximum dog leg which might be allowed. This all leads to a smoother and more regular directional well.

The regular 100-ft cylinder can be further "zoned" or restricted for special reasons. Another well may be too close, or the engineer's opinion may be that the well should be "lined out" to penetrate a difficult zone, or perhaps geological considerations require greater exactness. An example of a zoned cylinder is shown in Fig. 5. The section of the cylinder shows a type of zoning required to prevent wells from passing too close to each other and the reduced portion near the surface is necessary because of close spacing. The section of the cylinder gives a very true picture of the actual "dog leg" or bend and also shows exactly where the bore hole is located in the cylinder at any particular depth.

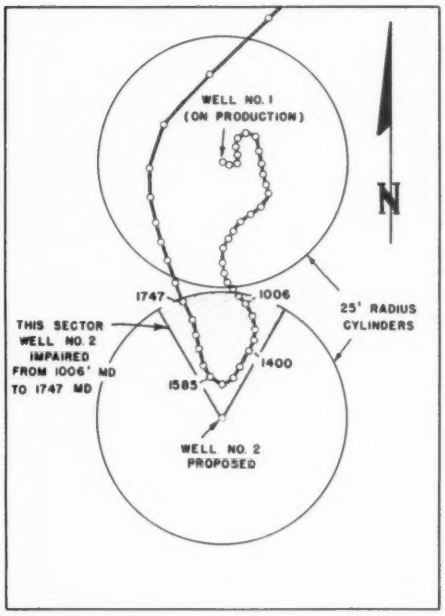


FIG. 5. Plan of cylinder of proposed well showing an impaired sector caused by interference from a producing well.

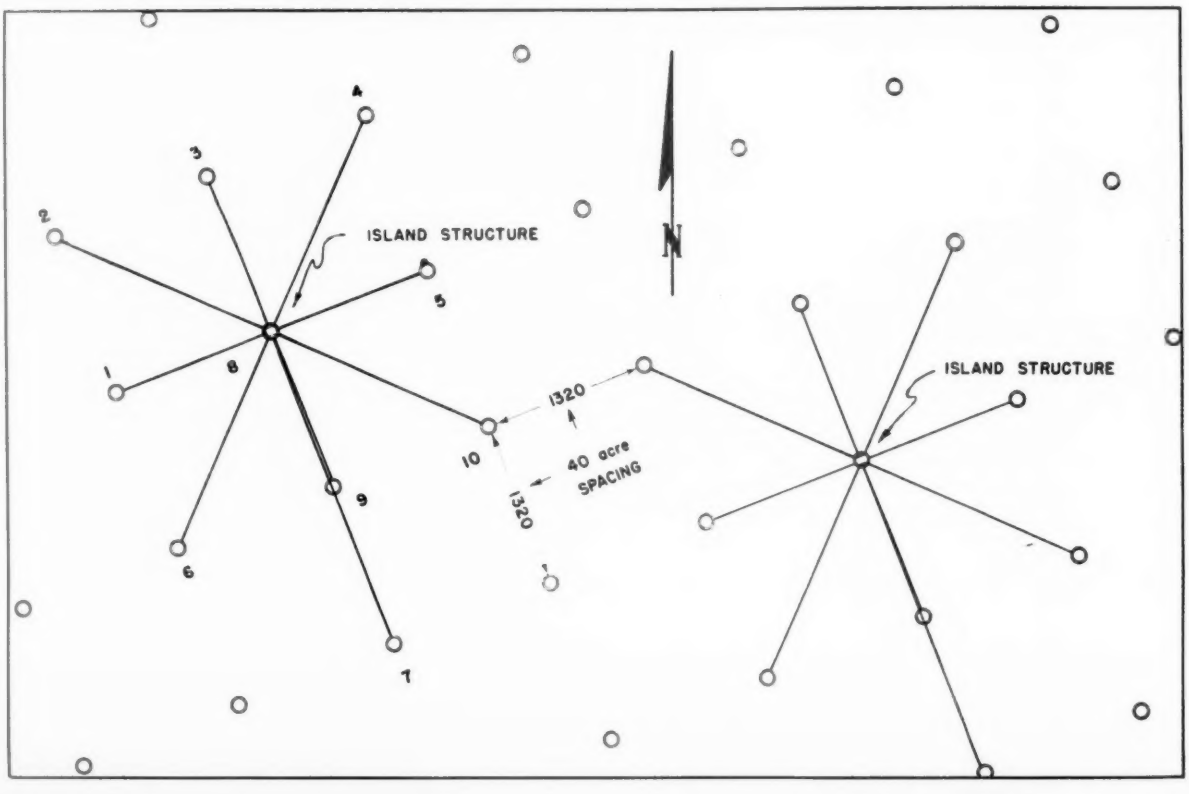
Cylinder drilling has been the major factor in the recent improvements in directional drilling procedures. The overall picture shows that it has given the engineering control necessary to drill better wells at a lower cost and with greater efficiency.

Directional drilling companies that have been in this type of work for years have the facilities and personnel enabling them to be of assistance to a company which does not have sufficient data on hand.

● **Directional tools.** The planning of a directional program would not be complete unless consideration were given to the use of the proper deflecting tools and allied equipment necessary to complete the job. The program should be developed in a manner so that the most effective tools and equipment available can be used on the directional work. The drilling equipment should be rigged with the necessary sand line, etc., so that fast means of surveying can be used. If the drift angle given in the proposal is low, non-magnetic drill collars might save rig time. High drift angles can be successfully surveyed with "trigger" bits and retractable equipment.

Full gage deflection tools should be run if the formation and hole size permit in order that valuable rig time can be saved. The use of the knuckle joint or the whipstock can be based upon such factors as hole size, depth, and formation. In order to achieve smooth changes of angle and to be able to maintain the course of the well the proper

FIG. 6. Plan of marine structure showing directional wells radiating to bottom locations.



types of reamers and drill collars must be used. The best results are gained by using spiral roller type reamers which provide good stabilization and a uniform contact with the wall of the well bore.

● **Casing program.** The casing program that is chosen for a directional well generally will vary slightly from that which would be chosen for a straight hole. The bending stresses that are set up in the casing by the curvature of the hole are small enough to be disregarded; it is good practice, however, to increase the thickness of the casing through the curved portion of the well bore to resist wear from the drill pipe. Many operators also follow the practice of running one grade better casing on directional holes than they would have used on a comparable straight hole. On very deep and long directional jobs or when difficult directional drilling conditions are encountered, the casing program may be altered so that a protective string can be set to safeguard the upper portion of the hole.

Casing will, in the majority of cases, run as easily in a controlled drilled hole as in a straight hole and modern directional drilling practice does not call for reduction in casing size for a given size hole. In fact, the constant use of wall reamers in directional drilling procedures keeps the well bore in good condition and many operators have now found that the reaming operations which are ordinarily done prior to running casing can be eliminated. Cementing through perforations is not considered good practice in high angle directionally drilled wells unless the cement points are first block under-reamed to permit better distribution of the cement. In all high angle wells stiff spring stabilizers should be used on and near the shoe joint to centralize the casing in the well bore and prevent the cement from channeling.

● **Typical example.** The following example illustrates one solution to the problem of planning a multiple well directional drilling program for offshore locations with the geological, mechanical, well spacing, and marine structure conditions given. Although it undoubtedly is not the only possible manner in which the planning can be done, it is a practical solution. It allows for the use of the data previously discussed. Assumed conditions are as follows:

Geological: Oil structure is nearly horizontal. There is not enough dip to affect well spacing.

Oil structure considered to be sufficiently productive to warrant economic production on one well to forty acre spacing.

Top of oil sand is at 8500 ft vertical depth. Thickness of productive zone is 250 ft; therefore, terminal depth is 8750 ft vertical depth approximately. There is no evidence of an oil zone below this depth.

Formation to be penetrated: unconsolidated; surface to approximately 500 ft; balance is sand, shale, and sandy shale with numerous hard shells at points between 1400 ft and 1625 ft depths. Lime formation occurs from 6850 ft to 7250 ft vertical depth (400 ft thick). Rock bits must be used in the latter stratum.

Mechanical: Casing program: 13⅜-in. casing 0 to 800 ft vertical depth.

7-in. casing 800 ft to 8500 ft vertical depth.

5-in. liner in oil zone.

Hole sizes to be 17-in. from 0 to 800 ft vertical depth.

10⅝-in. from 800 ft to terminal depth.

Drilling equipment is adequate to penetrate to depth specified; 4½-in. full hole drill pipe is to be used in conjunction with directional drilling surveying type bits and non-magnetic drill collars.

Wells to be drilled are expected to flow.

It is contemplated that oil produced will be pumped to storage on mainland through submarine lines.

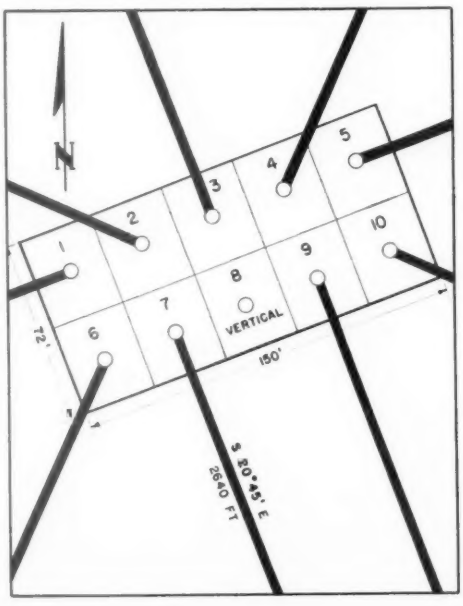
Well spacing: Spacing will be 26 ft center-to-center of casing heads of completed wells.

Island structure can be situated so that courses of directional wells will radiate from marine structure without necessity of crossing each other.

Marine structure: Structure is located in the open sea about two miles offshore where the depth of water is 20 ft at low tide. Tidal range is about 8 ft.

The drilling island is presumed to be a steel sheet-pile structure (cofferdam) tied across with steel tie rods. Earth fill is made inside the sheet-piling with a bearing-pile mat structure of sufficient strength to support oil derricks. Erosion at the base of the structure is minimized with heavy stone riprap. Structure will be rectangular in shape with 72 ft by 150 ft top surface. This will accommodate ten wells on spacing previously specified.

FIG. 7. Detail of island showing surface locations of nine proposed directional wells.



Power generating units, pipe racks, mud pits, bunk houses, etc., will be installed on barges moored alongside the island.

Directional drilling: Increase of drift is to be not over 2°30′ per 100 ft drilled. Maximum dog leg will not exceed 2°30′ in 50 ft or 5° in 110 ft.

The type of well chosen will be one that increases in drift at a uniform rate to the maximum and maintains this angle to bottom. Although it is anticipated that wells should flow in their early life, when pumping is necessary fluid pump and sucker rods will be in alignment. By penetrating oil zone at the maximum drift angle more productive sand will be exposed. This type of well is being chosen since no productive upper sands are known to exist. If, in the future, a productive sand is discovered at a greater depth than 8500 ft to 8750 ft vertical depth, it may be produced on similar well spacing by pulling the liners and redrilling the wells. This can be accomplished by straightening them at a uniform rate of decrease in drift. The water string is sufficiently large to permit the drilling of 5⅝-in. hole if the wells are redrilled. A considerable saving of drilling time is effected on this type of well since the maximum angle is maintained to bottom, thus eliminating the necessity of slower drilling while the well is being straightened at bottom.

● **Solution of example.** The proposed bottom locations of the wells are laid out on 1320-ft centers (40-acre spacing); the site of the marine structure is chosen so that one well in the group may be drilled straight. (See Fig. 6, Well No. 8.)

As the geological formation is practically horizontal, bottom locations are selected which separate the horizontal courses of the wells as much as possible. (See Fig. 7.) The true bearing and distance from the surface location to bottom of each well is next scaled or computed. The middle point of the thickness of the oil zone (8625 ft vertical depth) is used as the bottom of the well when the well spacing is planned.

It has been proved through experience in directionally drilled wells that the maintaining of drift angles of less than 15° makes accurate control of the well course very difficult. Hence the maximum angles of all wells should be greater than 15°.

Bearing in mind that the weight of drill pipe (and sucker rods when the well is pumped), as well as the rate of increase in drift per 100 ft drilled below the deflection point, have a direct bearing on the tendency of the drill pipe to keyseat (or the sucker rods to wear tubing) the amount of straight hole made before deflecting the well should be as great as possible. Economically this is advantageous since the straight hole is normally cheaper to drill.

Limiting the last two considerations mentioned above is the fact that it would be preferable to drill straight hole through the shells between 1400 ft and 1625 ft and the lime stratum between 6850 ft and 7250 ft or to have the

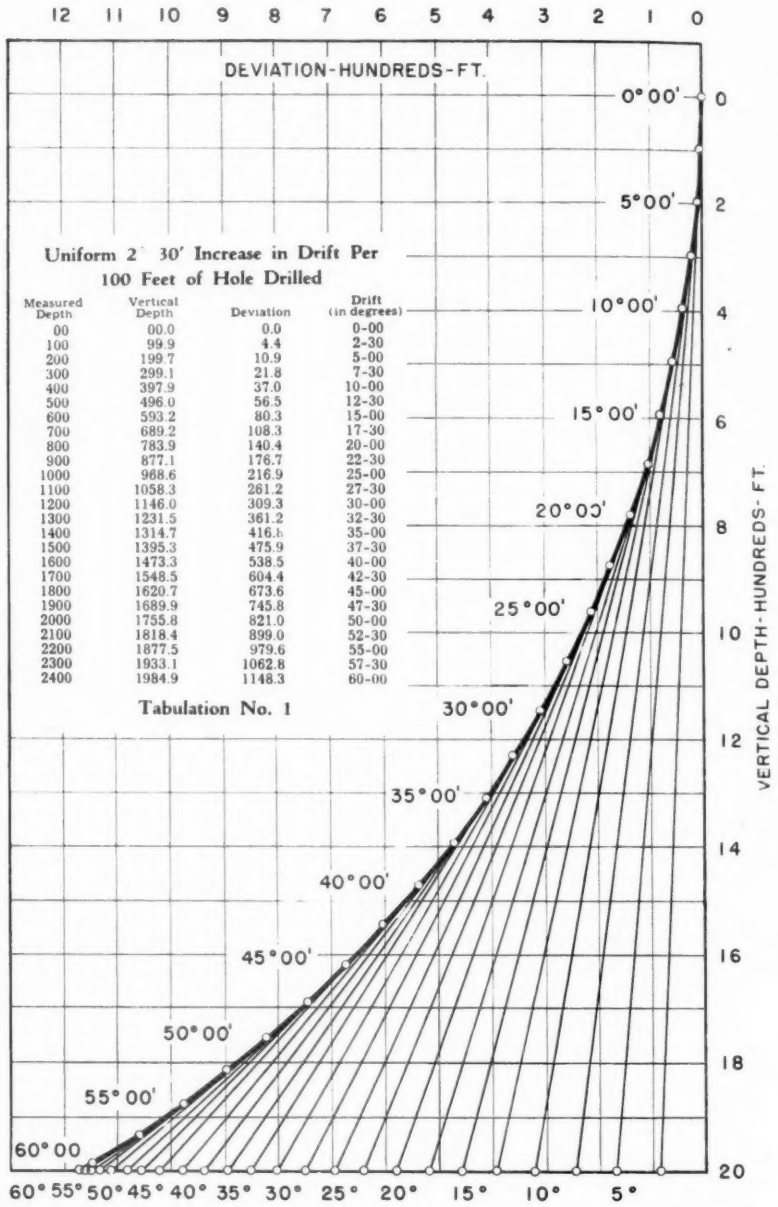
drift increased to maximum before either of these depths is reached. Either solution would eliminate the necessity for doing deflection work in formations not ideal for the setting of deflection tools.

● **Proposal for well No. 7.** As each of the nine directional wells (No. 8 is straight) has a different deflection distance to reach its proposed bottom location, each well must be considered separately. In this example then a complete directional drilling plan will be perfected for No. 7 well which requires the greatest deflection. The course of this well is S 20° 45′ E and the distance to the ideally spaced bottom at 8625 ft vertical depth (center of the thickness of the oil sand) is just 2640 ft. (Note: It is considered that the vertical depth has been adjusted for the elevation of the top of the rotary table above sea level.) It will be noted that the direct course of No. 7 well comes very close to the planned course of Well No. 9. Any possibility of the holes coming in close proximity to each other except in their vertical portions can be eliminated by starting deflection at different depths. Obviously it would be most convenient to start deflecting Well No. 7 at a shallower depth than No. 9 since the former well must travel a greater distance.

To ascertain a rough approximation of the minimum deflection angle necessary, the deviation distance (2640 ft) is divided by the total vertical depth of the well (8625 ft.) The natural tangent obtained (.3061) would be for approximately 17° drift. Thus it is shown that the well will necessarily be above the minimum of 15° decided upon. With this amount of deflection necessary, the well must pass through the lime stratum at 6850 ft to 7250 ft at the maximum drift since it obviously would be impossible to deflect the well 2640 ft in 1375 ft of vertical depth. However, it would be advantangeous to start deflecting the well below the unconsolidated surface formations and if possible deeper than the zone of shells from 1400 ft to 1625 ft depth.

To progress toward a more definite determination of the starting point for deflection, 2000 ft is taken as a round figure which is safely below the bottom of the zone of shells at 1625 ft depth. By dividing the deflection distance of 2640 ft by the balance of the vertical depth (6625 ft), 0.3985 or the natural tangent of 21°45′ drift is obtained as an answer. As this angle is nearest to 22°30′, which appears in the estimating chart mentioned below, the latter figure (22°30′) will be considered to be the necessary maximum deflection angle.

By inspection of Fig. 8 it is ascertained that 900 ft of measured depth will be required to increase the drift from 0°00′ to 22°30′ at a rate of 2°30′ increase per 100 ft of drilled hole. From Tabulation No. 1 (Fig. 1) it is noted that the deflection distance at the 900 ft measured depth point is 176.7 ft and the corresponding vertical depth is 877.1 ft. (See also Fig. 9.) If 176.7 ft is subtracted from the total deflection of 2640 ft, the remainder obtained is 2463.3 ft.



Measured Depth	Vertical Depth	Deviation	Drift (in degrees)
00	00.0	0.0	0-00
100	99.9	4.4	2-30
200	199.7	10.9	5-00
300	299.1	21.8	7-30
400	397.9	37.0	10-00
500	496.0	56.5	12-30
600	593.2	80.3	15-00
700	689.2	108.3	17-30
800	783.9	140.4	20-00
900	877.1	176.7	22-30
1000	968.6	216.9	25-00
1100	1058.3	261.2	27-30
1200	1146.0	309.3	30-00
1300	1231.5	361.2	32-30
1400	1314.7	416.6	35-00
1500	1395.3	475.9	37-30
1600	1473.3	538.5	40-00
1700	1548.5	604.4	42-30
1800	1620.7	673.6	45-00
1900	1689.9	745.8	47-30
2000	1755.8	821.0	50-00
2100	1818.4	899.0	52-30
2200	1877.5	979.6	55-00
2300	1933.1	1062.8	57-30
2400	1984.9	1148.3	60-00

Tabulation No. 1

FIG. 8. Graphic chart for estimating angles of directionally drilled wells.

This last amount of deviation is to be attained with an average drift angle of 22°30′. Hence, 2463.3 ft is divided by the tangent of 22°30′. The result, 5947.1 ft, is the vertical depth necessary to attain the deviation of 2463.3 ft. The sum of 5947.1 ft and 877.1 ft is 6824.2 ft. This is the vertical distance consumed by the deflected hole from the point at which the deflection is started. The result of subtracting 6824.2 ft from the total vertical depth of the well (8625 ft), is 1800.8 ft vertical depth. This figure represents the depth at which deflection is to be started. (Vertical depth and measured depth are identical at this point since the upper hole is considered to be vertical.)

Having established the theoretical point at which to start deflecting the well, the vertical depth of the point at which the well will attain the maximum deflection is found by adding 877.1 ft to the deflection starting point. This sum is 2677.9 ft vertical depth. The measured depth of this point will be 900.0 ft plus 1800.8 ft or 2700.8 ft measured depth. By dividing the vertical distance during which the well averages 22°30′ drift (5947.1 ft) by the cosine of 22°30′ (0.9239) the measured depth for the corresponding portion of the well is found to be 6437.0 ft measured depth. Adding this figure to 2700.8 ft gives 9137.8 ft. This is the measured depth corresponding to 8625 ft vertical depth.

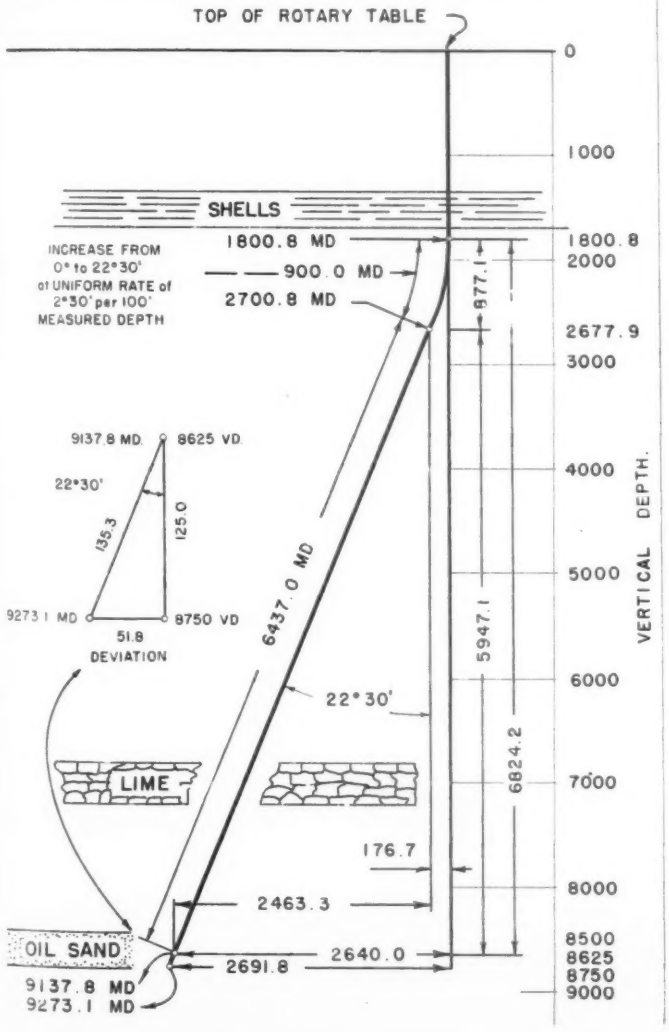
There remains the deviation and measured depth to be computed from 8625 ft vertical depth (center point of the thickness of the oil zone) to 8750 ft vertical depth (the bottom of the oil sand). The angle (22°30′) and the vertical depth (125.0 ft) of this small triangle are given. By use of the tangent and cosine the measured depth of 135.3 ft and deviation of 51.8 ft are computed.

These figures are added to the appropriate measured depth and deviation figures for 8625 ft vertical depth. Thus the measured depth is 9273.1 ft and the deviation is 2691.8 ft at the terminal depth of 8750 ft vertical depth. (Note: Although the thickness of the oil sand is but 250 ft, by penetrating it at a 22°30′ drift, 270.6 ft of sand is exposed. This represents a gain in exposed productive sand of approximately 8.3 per cent. The percentage increase in exposed sand in a directional well in comparison to a straight hole naturally is much greater as the angle of the well is increased.)

The results of the calculations may be tabulated as follows:

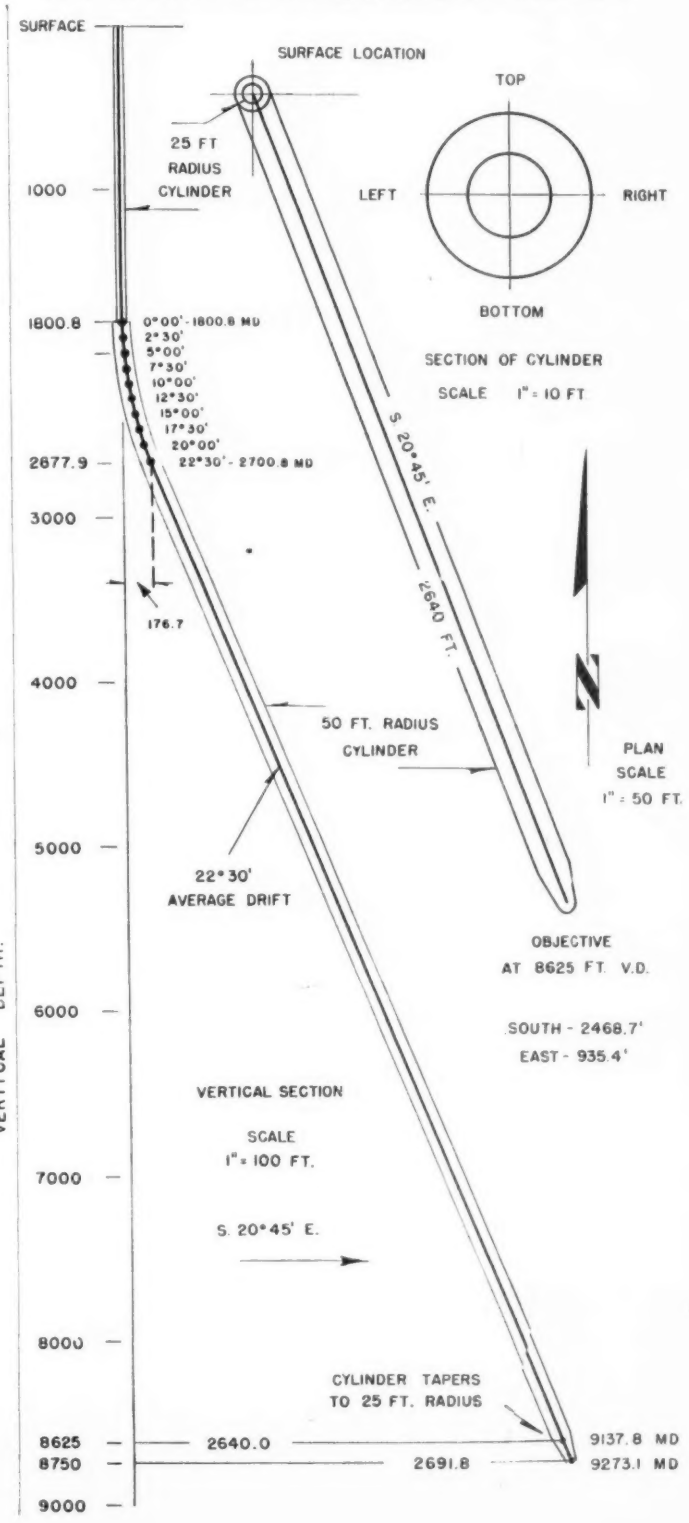
Measured depth	Vertical depth	Deviation	Remarks
1800.8 ft	1800.8 ft	0.0 ft	Point at which deflection is started.
2700.8 ft	2677.9 ft	176.7 ft	Point at which drift (by uniform rate of increase from 0°00′ to 22°30′ at uniform rate of 2°30′ per 100 ft drilled) has attained the desired maximum.
9137.8 ft	8625.0 ft	2640.0 ft	Point at which well will arrive at center of thickness of oil zone.
9273.1 ft	8750.0 ft	2691.8 ft	Point at which well will intersect bottom of oil sand.

FIG. 9. Section to accompany computations on Well No. 7.



● **Drafting the proposal drawing.** With the above information at hand a directional drilling proposal is drafted. A directional drilling proposal includes a plan view, a vertical section of the proposed well made in the plane of the well course, and a section across the cylinder in which the well is to be drilled. This proposal is drafted on cross section paper or cloth in order that it may be reproduced and especially so that the survey of the well may be plotted upon it as the well is drilled. The directional drilling engineers will use a copy continuously during the time in which the well is being drilled. They habitually plot the course of the well on all three sections in order to formulate their future control plans. Such a proposal for Well No. 7 is illustrated in Fig. 10. A cylinder has been described about the proposed course of the well on both the plan and vertical section. The cylinder has a 25-ft radius from the surface to

FIG. 10. Directional drilling proposal for Well No. 7.



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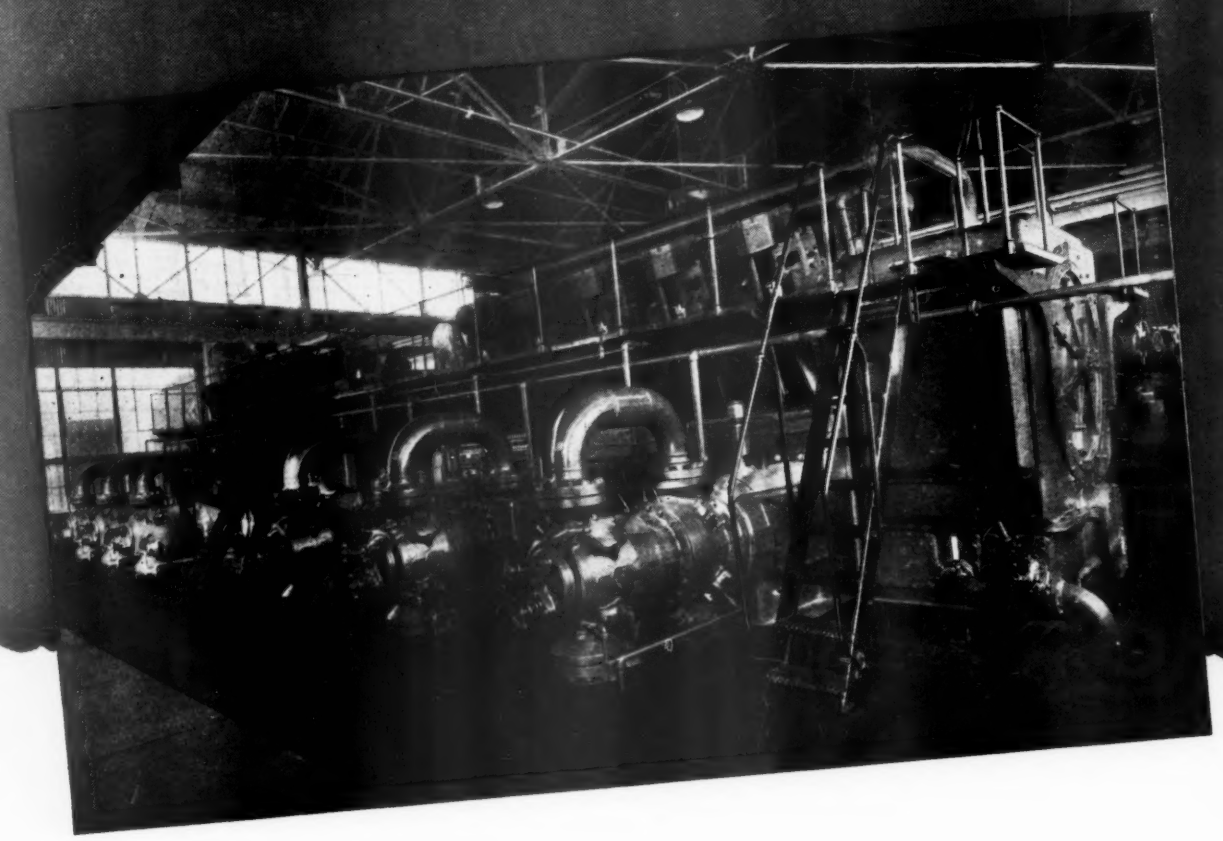

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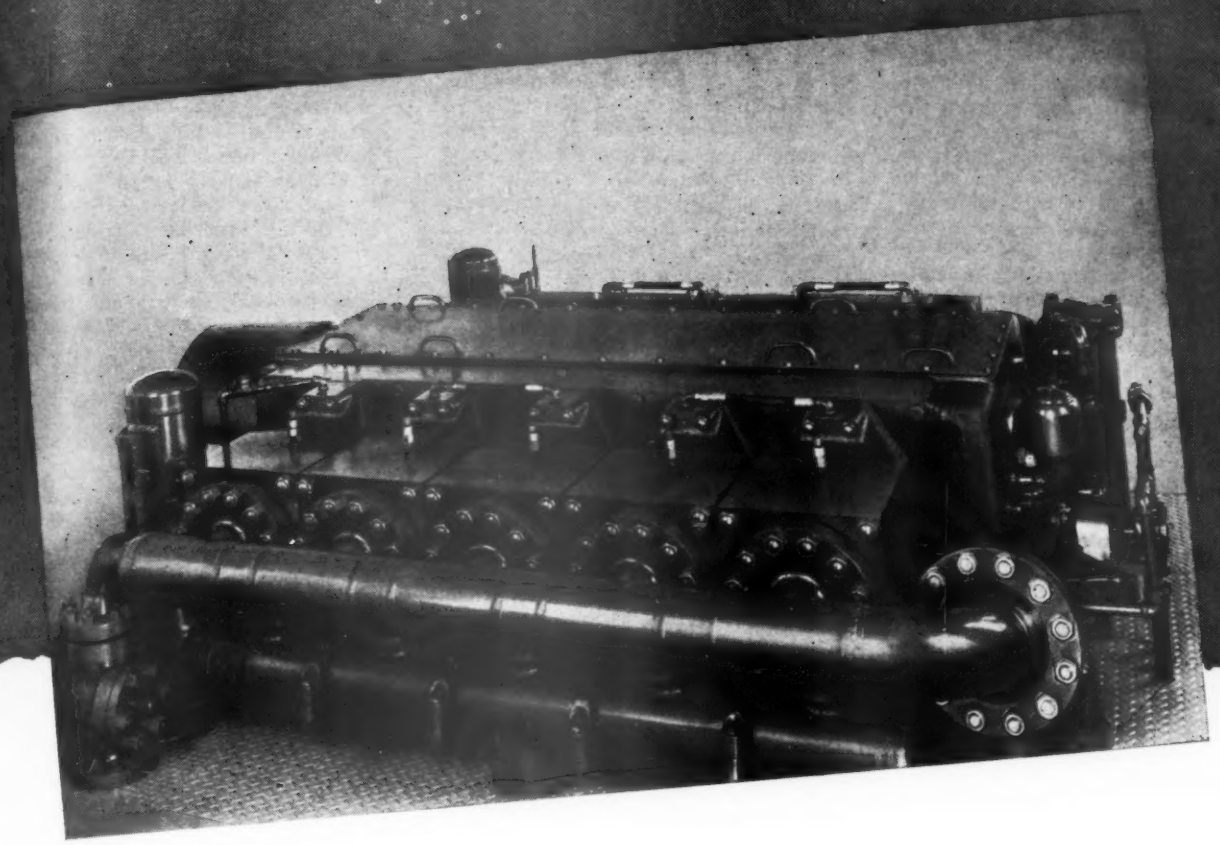

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the start of deflection (1800.8 ft measured depth.) At this point the radius increases to 50 ft, and the cylinder is this size to 9000 ft measured depth. There it starts to taper to a 25-ft radius cylinder at the terminal depth. The radius of the cylinder is small where the well is straight. The well spacing of 26 ft permits no larger cylinder for this and the adjoining wells from the surface to the deflection point. After deflection has been started the well can be allowed more latitude, hence the 50-ft radius cylinder. Since it is desired to keep the well spacing as accurate as possible in the oil sand, the cylinder is gradually tapered from 50 ft to 25 ft radius, reaching the minimum at the terminal depth. A typical section across the cylinder is shown on the proposal in order that the exact location of the well may be made in relation to the cylinder at that point.

● **Directional drilling and surveying procedure in accordance with proposal.** Assuming that the proposal illustrated for Well No. 7 shows no interference with the similar proposal made up on the remainder of the directional wells in the group to be drilled from the island, actual drilling can be commenced. For purposes of illustration it will be presumed that Well No. 7 is the next to be drilled after No. 8 (the straight well). As the location of the well must be known at all times, it is essential that an accurate survey be maintained up to date as drilling progresses. This is achieved by running an open hole type single shot on sand line, a regular or inside single shot down the drill pipe into a special non-magnetic drill collar, or by taking directional readings with a single shot run out through a trigger type or retractable coring type bit. Drift and direction readings are taken at intervals of not over 100 ft so that an accurate survey may be obtained. It is essential that the survey readings be taken at short enough intervals to insure a good survey. It should be borne in mind that the accuracy of well surveying varies inversely with the depth. Probably the greatest accuracy of magnetic surveys is no better than 3 ft in location per 1000 ft drilled. As the drift and depth increase the limits of error become greater. During the drilling of the straight portion of the well to the depth at which deflection is started the survey readings are computed and the location of the well is plotted on both the plan and vertical section of the proposal. On the plan the location of the well is plotted by rectangular coordinates. In plotting on the section the plotted point on the plan is projected on the plane of the proposed course of the well. This distance is scaled from the surface location. Used in conjunction with the vertical depth the well position is plotted on the vertical section. The vertical hole to shallow depths can be drilled within a 25-ft radius cylinder by careful drilling methods and observation of the best straight hole drilling practices.

● **Drilling and surveying procedure in accordance with proposal — deflected hole.** After completion of the hole to 1800 ft depth, the directional drilling engineers are put in charge of the well in so far as the directional drilling aspects are concerned. The appropriate type of deflecting tool will be oriented into the hole at this point, faced to increase the drift of the well in the proposed direction (S 20°45′ E). The directional drilling crew takes sufficient single shot pictures to be sure of the location of the well at all times. They recommend drilling setups, (types of bits, reamers, and drill collars) and their use in so far as speed of rotation and weight on the drilling bit, pump pressures, etc., are concerned. All of these factors together with the type and bedding of formations encountered in drilling are of importance in directional drilling practice. They vary widely with different structures and localities. Normally the engineers plot the location of the well as the single shot readings are taken. In their planning they use the section of the cylinder (see Fig. 10) on the proposal. The distance, right or left, is scaled on the plan from the proposed well course to the actual course of the drilled well. This measurement is made normal to the proposed well course. In the same manner on the vertical section the distance the drilled well is above or below the proposed well course is ascertained. These distances are used as ordinate and abscissa in plotting the location of the well in the cylinder. The center of the circle is considered the proposed well course. The control engineer thus is able to check the placement of the well in the cylinder after each single shot reading has been taken. The location of the well within the cylinder is the basis for their recommendations as to methods to be used in drilling. Aside from noting the effect of different drilling setups and methods which they recommend, the control men try to anticipate and provide for eventualities which might occur as the well is drilled deeper. Thus they set deflecting tools in such a manner that if an unexpectedly large dog leg is obtained from a deflecting tool it might be said that the successful directional drilling engineer is planning 300 to 400 ft ahead of the bit.

● **General recommendations covering the drilling of all wells from one island.** In drawing proposals for each of the directional wells of a group the interrelation of the wells must be considered. The deflected portions of the wells can best be separated by commencing the deflections at different depths. In cylinder drilling if the same rate of increase in angle is used on all wells they will tend to stay separated although they may follow nearly parallel courses. The normal sequence for drilling wells is to drill the lower angled wells first. A major portion of the experience gained in drilling these wells will be of value when those maintaining higher drifts are attempted.

It is probable that numerous minor changes will be made in the program as the individual wells are drilled. Hence it is wise to reconsider each proposal in light of the experience gained in the drilling of the preceding well. Often a well will encroach upon the cylinder of a well for which the proposal has been drawn but which has not as yet been drilled. In some cases where directional wells are numerous it is imperative that the course of a new hole come very near the casing of another well. When this condition arises the section of the cylinder is shown with a sector which must not be entered between certain depths during the drilling of the new well. Such a situation is illustrated in Fig. 5 in which a sector of a cylinder is not to be entered by the new well between 1006 ft and 1747 ft depths.

It is advisable to employ similar surveying methods on all of a group of wells drilled in juxtaposition. For example, if the open hole method of running a single shot is used, its use should be continued throughout the whole group of wells. Thus any inherent errors in the methods of using the surveying equipment will not affect the correlation of the wells.

● **Conclusion.** It is the sincere hope of the authors that the above discussion and consideration of the factors involved in the planning of a multiple well directional drilling program for offshore locations will be of benefit to those engineers who may be called upon to plan programs of this type.

● **Acknowledgments.** The authors wish to take this opportunity to express their appreciation to the Eastman Oil Well Survey Company for permission to prepare and present this paper; to D. S. Johnston of the Signal Oil and Gas Company for his critical review and suggestions; and to the helpful cooperation of the many oil men with whom actual directional drilling programs have been planned and carried out, thereby supplying the practical foundation of experience upon which this paper is based.

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Offshore drilling development*

By D. A. McGee, A. T. F. SEALE and G. O. DANIELSON, Kerr-McGee Oil Industries

● **Abstract.** The exploration and drilling for oil off the Louisiana Coast in the open waters of the Gulf of Mexico has assumed added importance with the discovery of oil in the well known as the Kerr-McGee Oil Industries, Inc., et al., Block 32, No. 1, Ship Shoal area, south of Terrebonne Parish, Louisiana. This well was drilled using a combination small platform and floating barge. The methods used, especially the use of the floating barge for a warehouse, living quarters, liquid storage, and mud pits and auxiliary equipment, are innovations with respect to marine drilling operations. The block 32 discovery well was completed through perforations from 1734 to 1750 ft, flowing approximately 40 bbl per hr of 25.3° API gravity oil through ½-in. choke on tubing.

The discovery of oil in Kerr-McGee Oil Industries, Inc., Phillips Petroleum Company, and Stanolind Oil and Gas Company's State of Louisiana Block 32, No. 1 (Lambert Coordinates: X = 2,053,632.45 Y = 161,712.70), 10.5 miles from land in the open waters of the Gulf of Mexico, off Terrebonne Parish, Louisiana has served to intensify the search for oil in this small segment of the vast continental shelf area of the Gulf of Mexico and has turned the interest of the American oil industry to potential oil bearing territories lying under the continental shelves of other parts of the world. The exploration of the Louisiana coastal belt out to a distance of 27 miles, to which distance Louisiana claims sovereignty, has been in progress to a small extent for several years but in the past two years the exploration has been greatly intensified. In January, 1948, at least 20 companies were aggressively engaged. The exploration has, of course, all been geophysical, the seismograph and diving bell type gravity meter being the two methods used.

In January, 1948 there were 28 reflection seismograph crews and 2 gravity meter units operating off the Louisiana Coast. In January, 1947 there were 14 seismograph and 4 gravity crews whereas in January, 1946, there were 2 seismograph and no gravity meter crews. In January, 1946, one of the seismograph units was of the refraction type and in January, 1947 four were refraction units while in January, 1948, all units were of the reflection type. It is evident from these figures that the refraction seismograph and the diving bell type gravity meter were favored for reconnaissance in the early phases of this exploration. As the equipment and techniques for reflection seismograph work on water have been rapidly improved, the other two methods have been replaced off the Louisiana Coast since reflection seismograph data is much more precise and accurate in defining salt dome prospects. In the early phase of the open water exploration reflection work was slow and expensive. Loss of working time due to rough water, especially from November through March, was large. With the development of the geophone tow cable, floated explosives, and electronic surveying, along with better marine equipment, especially larger boats, it is now possible to work even in rough weather. On a good day more than twice as many stations can now be observed on water as can be observed on land. The unit cost of reflection work and the speed of coverage is such that it is no longer desirable to pursue slower, less accurate methods of geophysical exploration.

Before performing geophysical exploration work within Louisiana waters a permit must be secured from the State Conservation Department, from the Wild Life and Fisheries Department, from the Police Jury in the contiguous parish, and from the United States War Department through the Army Engineers. The granting of these permits was, and is, fairly routine. Leasing of the water covered state lands has been handled by the Louisiana Minerals Board in a business-like and efficient manner. The Board in the past has held sales when a request or requests have been made for leases to be put up for sale. In order to prevent disclosing the location of a prospect, the requesting companies have designated large areas to be advertised for sale. The Minerals Board limits the maximum size of a single lease to 5,000 acres. The lands are advertised in tracts of 5,000 acres or fraction thereof. Sale is by sealed bid and the bidder must tender the full purchase price with each bid. Since late in 1945 the State has held nine sales of leases in the open waters and has realized a total of $16,890,913.00 for 1,951,936 acres of leases. It is estimated that at least 36 salt dome prospects have been mapped and leased in the coastal waters of Louisiana. Fig. 1 is a map of the Louisiana coastal belt. It shows the producing oil and gas fields on land and in the protected waters of the bays, swamps, and bayous. It also shows the Block 32 discovery in the Ship Shoal area, the Block 28 well (Lambert Coordinates. X = 2,013,562.6 Y = 154,713.82) now drilling, the dry holes that have been drilled in the unprotected waters, other presently drilling wells, and the approximate location of a number of leased but undrilled salt dome prospects. Water depths in five fathom intervals and the 27-mile state boundary are also shown. As would be expected the salt dome prospects underlying the water covered areas duplicate in type, character and density of occurrence those found on the adjacent coastal land belt. There are both deep seated and piercement type domes. There are domes with large structural closure and with relatively small closure. The pattern of their occurrence is very similar to that on land as the map shows.

As a result of the Kerr-McGee seismic work in the Ship Shoal area, two salt dome prospects were mapped, one a piercement type dome and the other a deep seated dome. Leases covering 20,000 acres on each prospect were obtained from the Louisiana State Minerals Board. Locations on each of these lease blocks were selected and carefully surveyed in by running survey lines from the U. S. Coast and Geodetic Triangulation Stations along the adjacent coast line and by triangulation from these same reference points. Test piling were then driven at each of the two locations selected.

Results obtained from the driving of three test piling at the Block 32 location and three at the Block 28 location, Fig. 2, indicated piling would be satisfactory for the foundation of the small platforms which were to constitute the stationary portion of the combination platform and floating barge arrangement which was selected after careful investigation and consideration of methods previously used as well as those methods proposed but untried. Since the load carrying capacity of an open ended steel piling is a function of the frictional resistance between the surface area of the pile and the penetrated material, it could be determined with reasonable accuracy what the required penetration of various size piling necessary for supporting a given vertical load would be. Calculation of the wind loads acting upon the structure was also made with confidence but numerous assumptions had to be made both with respect to the sea and wave action on the structure and the combining of the dead load and these two live loads. It was concluded that fewer piling of larger diameter would offer advantages in design both from the standpoint of resistance offered to wind and wave action and to lateral flexure. It should be stated that availability of material rather than economy dictated to some extent the final design of the structure. Since 24-in. OD seamless steel casing having a wall thickness of .512 in. and weighing 128 lb per ft could be acquired, it was used. This steel casing was fabricated and driven as piling on a spacing arrangement of from 10 to 15 ft on centers. It was felt that piling of this size would offer minimum resistance to wave and current action since an object of this shape in the

*Presented before Spring meeting of the Southwestern District API Division of Production, Plaza Hotel, San Antonio, Texas, April 14-15-16, 1948.

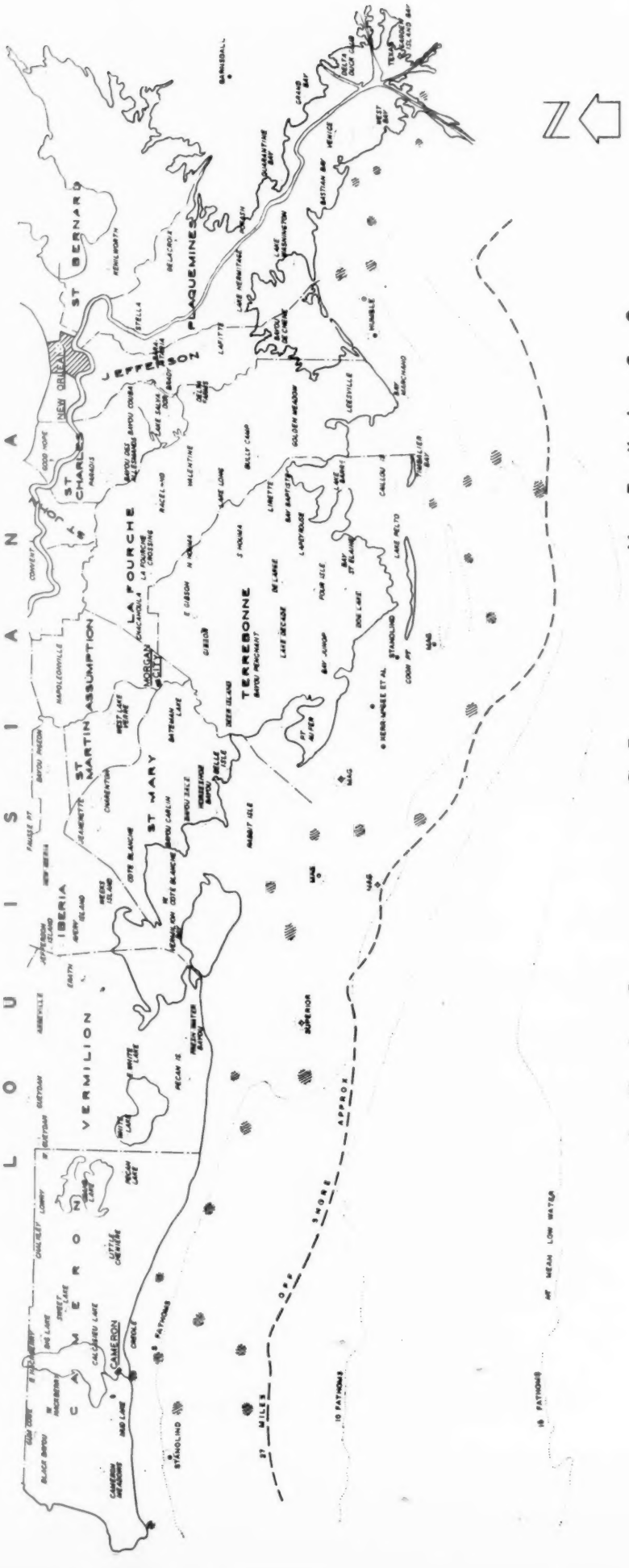


FIG. 1. Map of the coastal belt of Louisiana showing producing oil and gas fields and, cross-hatched, the approximate location of some of the offshore salt dome prospects that have been surveyed and leased.

water influences a zone roughly equal to five times its own diameter. The piling supporting the platform structure were braced with 9⅝-in. casing to a point 2 ft above mean low tide. The water depth at the Block 32 location was 18 ft, making a distance between the bottom of the bracing and the ocean floor of 20 ft which was unbraced. The top 30 ft of the ocean floor is composed of a very soft, unconsolidated material. The point of counterflexure or the point of effective lateral support for the piling acting as a fixed end column was estimated to be 40 ft below the ocean floor, or a total unsupported length of 60 ft was assumed. A layout plan of the structure, taking into account the distributed and concentrated loads peculiar to an oilwell drilling rig, was developed as shown in Fig. 3. This loading required a minimum of 50 tons safe bearing capacity on each of the 16 primary steel piling supporting the structure.

To provide a landing platform for materials transferred from the floating barge and to afford working space on the Vee door side of the derrick, a 15-ft section was added to the platform by placing one end of the floor beams on the cap supporting the front legs of the derrick substructure and the other on a 12-in. by 12-in. treated timber cap supported on six treated timber piling 105 ft long. This resulted in a platform 38 ft wide by 70 ft long with the primary section 38 ft by 56 ft supported by the sixteen steel piling, 24 in. OD by 140 ft long, driven to a penetration below the ocean floor of approximately 104 ft and the secondary section, 15 ft by 38 ft, resting on the 6 treated timber piling driven to an average penetration of 69 ft.

To serve as a buffer between the floating barge and the platform structure, and wholly independent of the structure itself, three creosoted timber pile dolphins, consisting of 19 piling each, were driven. On the back side of each dolphin three steel H-beam bearing piling were driven at an angle of approximately 30 deg. These brace piling were welded to a one-half inch thick semi-circular steel plate which in turn were attached to the dolphin by means of wire line wrapping at the top and bottom of the steel plate. These dolphins not only afford protection to the stationary platform structure, but aid substantially in the mooring of the stern and of the floating barge.

The long axis of the platform and the barge were located northwest-southeast with the bow of the barge pointed to the northwest. Since these are the directions of the prevailing winds, the arrangement offered the least area for wind resistance.

As can be seen from Fig. 3, the only equipment on the platform structure consists of the substructure and derrick, draw works, rotary table, shale shaker, drilling engines, day tank for water and fuel, small mud tank, and an auxiliary mud pump.

All of the remaining supplies and equipment required for drilling and completing a well in the open Gulf including mud pits, dry mud, cement and chemical storage, mud pumps, pipe racks, skid mounted cementing and electric log-

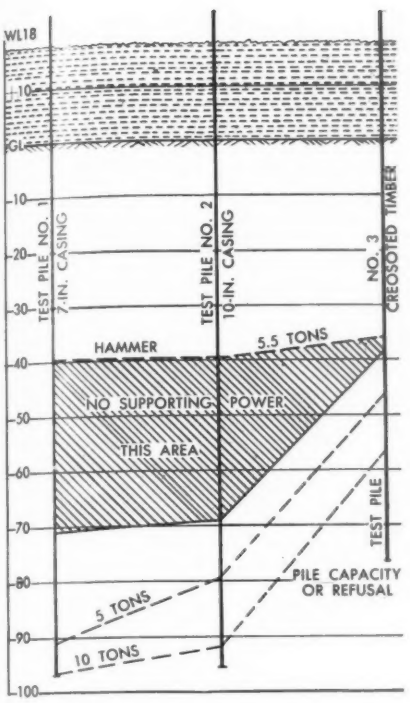


FIG. 2. Data procured from driving three test piling at Block 32 location in the Gulf of Mexico.

ging units, diesel fuel, drilling water, and complete quarters and galley for crews are carried on the floating barge.

As shown in the side elevation, Fig. 4, the small mud tank was incorporated into the front part of the engine substructure and the auxiliary mud pump located under and driven by vee belts from the drilling engines. The auxiliary pump and the mud tank on the platform were provided to afford a factor of safety and a degree of flexibility of operation. While it has not yet been necessary, it should be possible to continue drilling operations for probably 48 hr with the barge pulled off location. In any event circulation could be continued or the hole could be filled with mud prior to suspending drilling operations. Also shown in Fig. 4 is the relative position of the barge o the platform structure during normal drilling operations. Mud is pumped from the pits located in a lower hold section of the barge to the platform through a flexible steel hose. The return is through a telescoping hose arrangement between the platform and barge. Fuel, water, and cement are also transferred from the barge to the platform through flexible connections. All of these connections are designed for quick release using hammer unions. Drill pipe and casing are transferred from the barge to the derrick floor in an especially designed trough using the cat-line on the rig.

The floating barge portion of the combination platform-barge drilling arrangement is a converted YF Navy barge. These barges were originally designed for transporting and storing of cargo and supplies for the Pacific Theatre during the war. They have a cargo capacity of 2300 long tons and due to their unobstructed large open space both above and below decks were ideally suited for conversion to an auxiliary drilling barge. The overall size is 260 ft by 48 ft. The moulded depth from the bottom of the hull to the weathered deck is 15 ft and the deck house above the weathered deck is 13 ft. The space in the hull between the inner bottom and the weathered deck is divided into eight compartments, each 20 ft by 48 ft by 12 ft. There is an engine room aft and miscellaneous storage, salt and fresh water pressure systems forward. On the main or weathered deck is a weather tight cargo storage space 168 ft by 40 ft by 13 ft. Forward of this space are located quarters for a complement of ten men, a complete galley with 24 cu ft of deep freeze and 36 cu ft of storage refrigeration. On the top deck are located two electrically operated 5 ton stiff leg cargo handling derricks.

The conversion of the barge to an auxiliary drilling barge presented numerous problems from the standpoint of distribution of weight since so much of the drilling equipment, pumps, mud pits, pipe racks, etc., require a large concentration of weight in a relatively small area. Structurally, the barge was capable of supporting its capacity load of 2300 long tons uniformly distributed. Therefore under heavy concentrated loads such as the mud pits, mud pumps and engines, and pipe racks, additional reinforcement had to be provided. This was held to a minimum by careful placement of the equipment and storage areas as indicated in the inboard profile cross-section view, Fig. 5. Drilling mud and drilling water are carried below the main deck in the hull with the weight of the drilling mud, which is located on the port side, off set by the main mud pump, the mud mixing pump, their engines, and

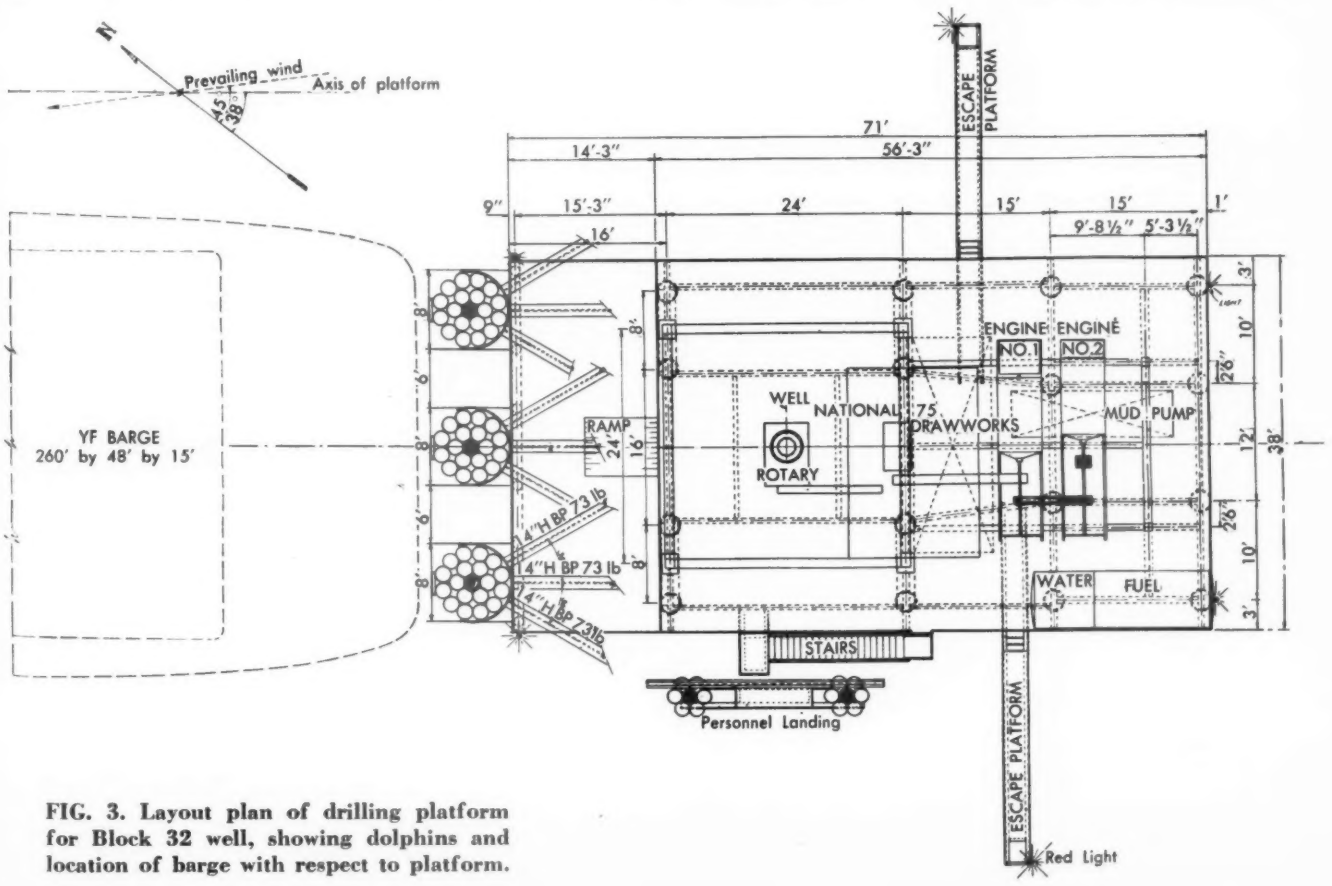
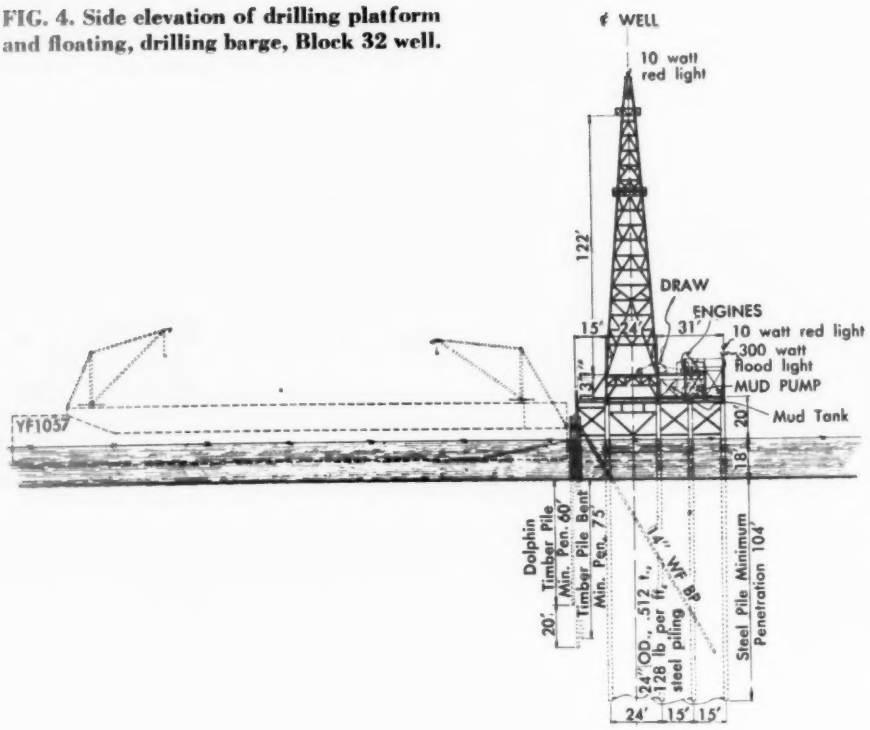


FIG. 3. Layout plan of drilling platform for Block 32 well, showing dolphins and location of barge with respect to platform.

FIG. 4. Side elevation of drilling platform and floating, drilling barge, Block 32 well.



the cementing unit which are all located on the starboard side on the main deck. The dry mud, weight material, cement and chemical storage area is located well forward on both sides of the main deck. Quarters, galley, hospital, lounge, and recreation rooms are located in the forepeak portion of the main deck with 20,000 gal of potable water, equally distributed, carried in the forward wing tanks. The pipe racks on the top deck are arranged so as to distribute their weight equally between port and starboard and slightly heavier to the stern. With the barge fully loaded, it trims from 6 to 9 in. by the stern, which is ideal for towing.

The stability of a floating body is measured by the distance its metacenter falls above or below its center of gravity. On the final design, with full load, this distance on the barge as converted is some 52 ft above the center of gravity which is unusually high for a vessel of this type.

The rotary drilling equipment used in the drilling of the Block 32 and 28 wells was designed for maximum operating performance at 7000 ft and 12,000 ft, respectively, for each of the two locations.

Although seismic information indicated that a hole of 4000 ft or less would be required to test Block 32 structure, equipment was installed of sufficient size and capacity to drill to 7000 ft. This consisted of a specially designed 577,000 lb capacity, 129-ft by 24-ft base derrick with a wind load rating of 125 mph without guys. This derrick was supported by a 12 ft nominal height by 24 ft base, 4-post, 6-truss, 1,000,000-lb corner load rating substructure. The drawworks and its two direct-driven prime movers were supported by a truss-type substructure into which was incorporated the platform and volume tank and sandtrap. In designing this rotary layout, special emphasis was directed toward space saving in order to hold the platform size to a minimum. The drawworks was powered by two 8½ in. by 10½ in. six cylinder diesel engines, each rated at 380 brake hp.

The hoisting string-up on Block 32 consisted of 200 ton capacity hook, blocks, links, and elevators, this rating being sufficient to handle heavy 5½ in. OD casing at its maximum setting depth.

The main slush pump, which was located on the floating barge, was a 7¾ in. by 18 in., 412 hp duplex power pump, driven by an 8½ in. by 10½ in. eight cylinder diesel engine with a continuous duty rating of 456 brake hp.

The mud piping on the barge and platform consisted of two separate and independent 4 in., 6000 psi working pressure systems. This was installed to insure continuous operation of the mud circulation system in the case of line failure at a critical stage in the drilling of the well. The barge and platform mud discharge systems are connected by 4 in. flexible steel hose and mud is returned to the pits on the barge through an 8-in. rubber hose running from the platform to the barge. A second or auxiliary slush pump was located under and belt-driven by the drawworks prime movers on the platform. This pump was a 7¼-in. by 15 in. duplex, rated at 294 brake hp input.

A third slush pump, a 7¼-in. by 10-in. duplex power pump was mounted in the barge and is used to mix mud, jet pits and transfer barge ballast and rig water.

Specially mounted diesel engine driven cementing equipment is located in the barge and is connected to the platform by a 3-in. 10,000 psi test line. Emergency connection of the cementing lines

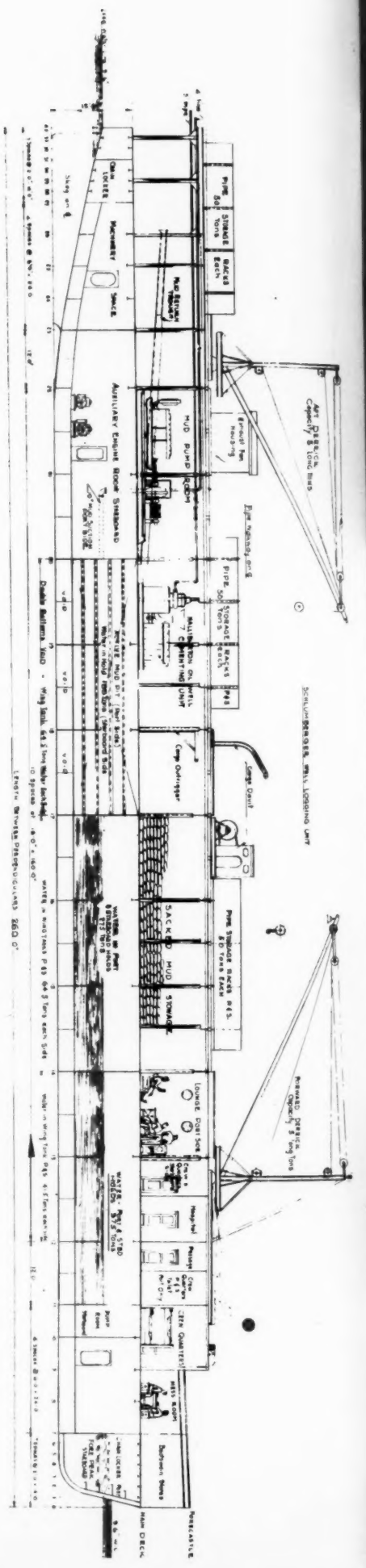
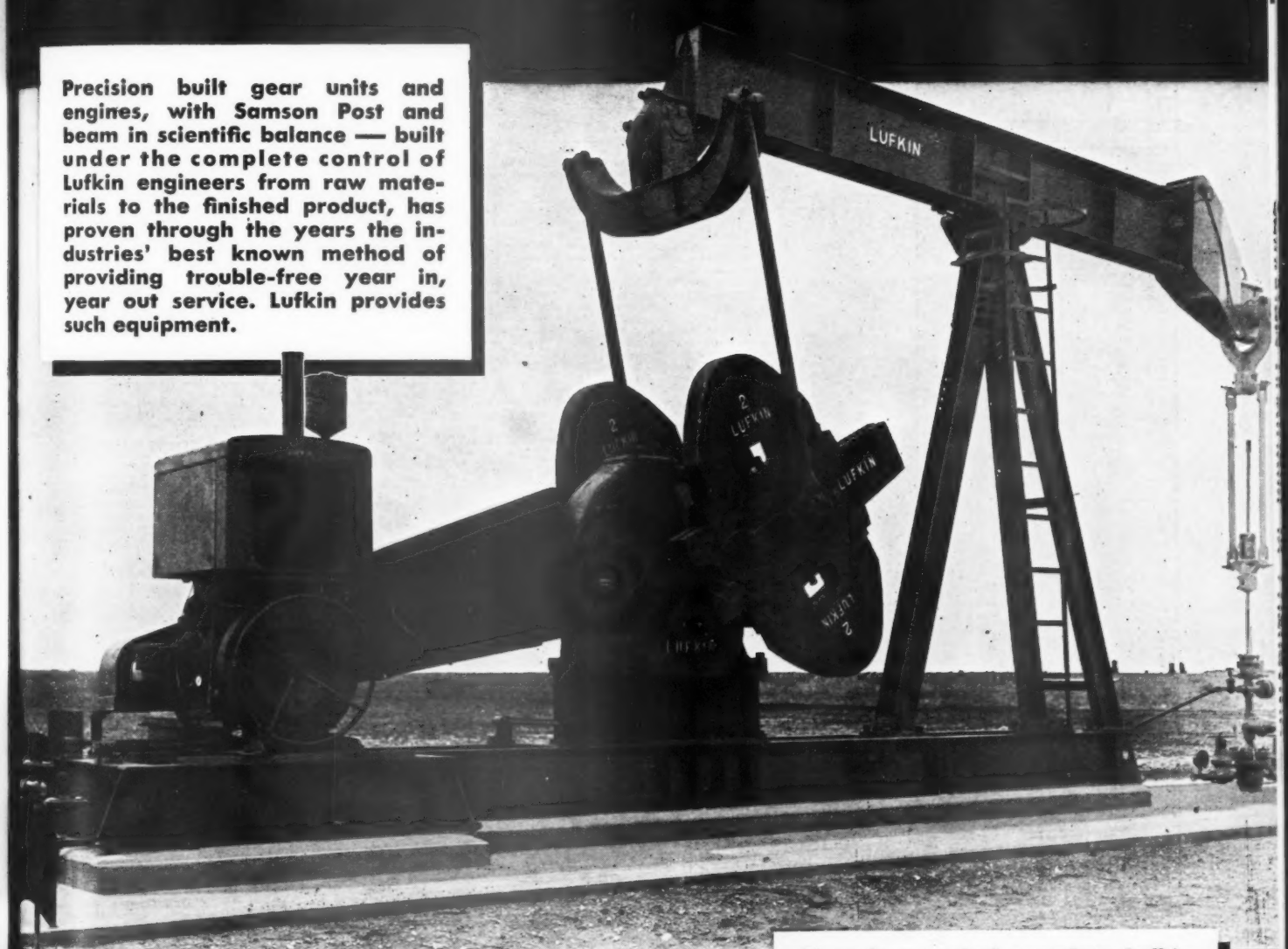


FIG. 5. Longitudinal inboard profile of converted YF drilling barge.

LUFKIN

Precision built gear units and engines, with Samson Post and beam in scientific balance — built under the complete control of Lufkin engineers from raw materials to the finished product, has proven through the years the industries' best known method of providing trouble-free year in, year out service. Lufkin provides such equipment.



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Here is a typical complete Lufkin installation—A No. 35 Lufkin Pumping Unit Assembly driven by a Lufkin-Cooper Bessemer gas engine. This job was completely Lufkin engineered and installed.

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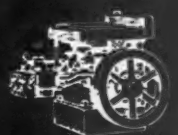

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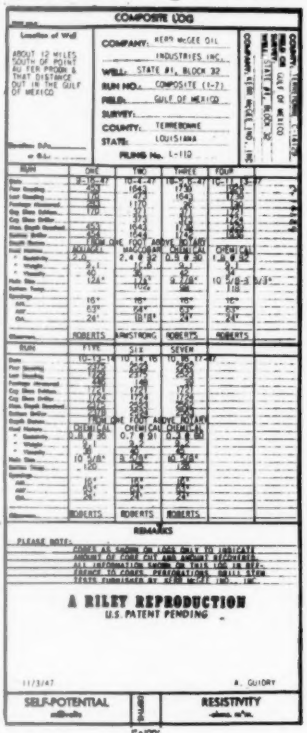
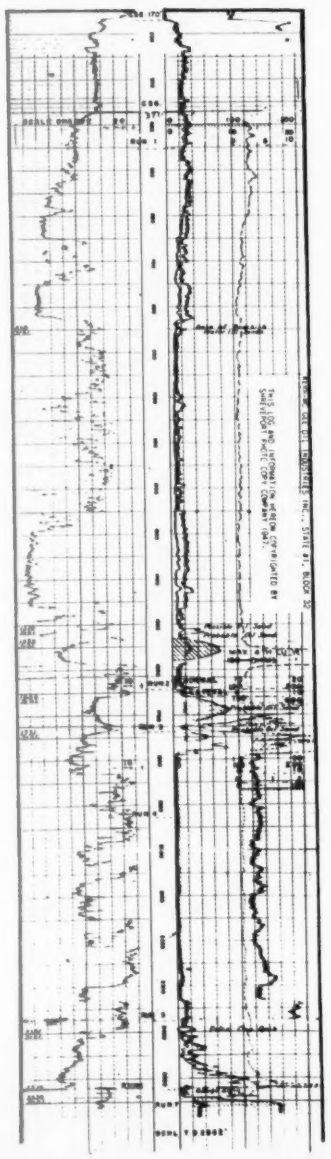
FIG. 6. Electric log of Block 32 well and record and description of cores taken.





HUGHES CONVENTIONAL BARREL

(1) 1644-1664' Rec. 5'0", light greenish gray silty shale with very fine silty sand laminae. Green shale streaks and fine light gray tight sand streaks. Practically entire core had fair to strong odor and with bluish-white fluorescence throughout except in dense shale streaks.
5'0"

(2) 1664-1684' No recovery. Cutting time 13 min.

(3) 1684-1699' No recovery.

REED WIRE LINE CORE

(4) 1743-1751' No recovery.

(5) 1751-1761' No recovery.

(6) 2378-2398' Rec. 10'0", gray shale, sandy shale with sandstone and cap-rock boulders (Gouge zone) interspersed throughout core recovered. Limestone boulders speckled with quartz grains. No odor or fluorescence.
10'0"

REED WIRE-LINE CORE

(7) 2514-2524' Rec. 0'8", very hard dark gray dense limestone with quartz grains speckled in limestone matrix. Questionable odor, fine fluorescence.
0'8"

SCHLUMBERGER SIDEWALL SAMPLES:

(1) 1509½' Rec. 1½', gray, finely arenaceous clay. No odor, taste or fluorescence.

(2) 1514' No recovery. Bullet not recovered.

(3) 1514' Gray, soft, medium-fine, even grain sand. Good odor and bright whitish blue uniform fluorescence. Saturation 13.30%.

(4) 1518' Rec. 1½" gray, soft, medium-fine, even grain sand. Good odor and even whitish-blue fluorescence. Saturation test not run.

(5) 1521' Bullet not recovered.

(6) 1522' Rec. 2" gray, medium-fine, soft, porous sand. Good odor and whitish-blue fluorescence. Saturation 20.00%. (Second sample partly shaly with saturation in sand streaks.)

(7) 1523' Bullet not recovered.

(8) 1538' Rec. 1¼" gray, medium-fine, soft, porous sand. Good odor and whitish-blue fluorescence. Saturation .033%.

(9) 1542' Bullet not recovered.

(10) 1546' Rec. 1" gray, medium-fine, soft, porous sand with brown clay streaks. Good odor and fluorescence in sand only. Saturation .044%.

(11) 1550' No recovery.

(12) 1550' Rec. 1" gray, soft, medium-fine sand with shaly streaks. Good odor and whitish-blue fluorescence in sand. Saturation 3.40%.

(13) 1557' No recovery.

(14) 1559' Rec. 1" gray, soft, medium, even grain sand. Good odor and brilliant uniform fluorescence. Saturation test not run.

(15) 1566' No recovery.

(16) 1572' Rec. 1" gray, medium to medium-coarse, soft, porous sand. Good odor and spotted blue-white fluorescence. Saturation .063%.

(17) 1585' No recovery.

(18) 1637' Rec. 2" gray, micaceous, argillaceous, medium grain tight sand. Fair odor and spotted fluorescence. Saturation: trace.

(19) 1637' Rec. 1¼" gray, medium, clean, soft, porous sand. Good odor and brilliant uniform bluish-white fluorescence. Saturation .060%.

(20) 1639' Rec. 1½" gray fossiliferous shale with thin laminae of fine sand. Lignite streak in center. Faint odor, bluish-white fluorescence in sand streaks. Oil trace.

(21) 1640' Rec. 1¼" gray, medium-fine, even grain, soft, porous sand. Good odor and even white-bluish fluorescence. Saturation .075%.

(22) 1660' Rec. 1" dark gray somewhat clayey fine sand. Good odor and bright uniform whitish-blue fluorescence in sand. Saturation 4.90%.

(23) 1670' Rec. 1" gray to tan stained (quebracho) soft, very porous medium grain sand. Good odor and bright whitish-blue fluorescence. Saturation not run.

(24) 1680' No recovery.

(25) 1691' No recovery.

(26) 1699' No recovery.

(27) 1710' No recovery.

(28) 1716' Rec. 1" gray, fine grain, somewhat clayey, soft sand. Good odor and bright blue-white fluorescence. Saturation 3.15%.

(29) 1733' Rec. 1" gray, soft, porous, clean, medium sand. Good odor and brilliant uniform blue-white fluorescence. Saturation not run.

(30) 1735' Rec. 1½" dark gray, fossiliferous, tight, sandy shale. Slight odor, spotted fluorescence. Oil trace.

(31) 1742' Rec. ½" gray, medium-coarse, soft sand. Mud contaminated and not sufficient for saturation test. Fair odor and fluorescence in sand.

(32) 1747' Rec. ½" gray, very soft, porous sand. Good odor and brilliant whitish-yellow fluorescence. Sample not sufficient for saturation test and badly contaminated by drilling mud.

(33) 1752' Rec. ½" gray, very soft, porous sand. Good odor and bright whitish-yellow fluorescence. Very poor sample. Saturation: trace.

(34) 1755' Rec. 2" gray, soft, mediu.n grain, porous sand. Good odor and bright yellow-white fluorescence. Saturation 1.52%.

(35) 1760' Rec. ¼" gray, soft medium grain, porous sand. Faint odor and fair fluorescence. (Poor mud contaminated sample.) Saturation: trace.

(36) 1763' Rec. 1½" greenish-gray shale with thin sand streaks. Fair odor and streaked fluorescence. Saturation: trace.

(37) 1769' Rec. 1½" greenish-gray shale and stained coarse to gravelly sand streaks. Fair odor and whitish-yellow fluorescence. Saturation 3.17%.

(38) 1771' Rec. 1¼" gray, soft, porous, clean, medium grain sand. Good odor and brilliant uniform whitish-yellow fluorescence. Saturation 6.12%.

(39) 1775' Rec. 1" same as above. Saturation 4.37%.

(40) 1779' Rec. 1¼" same as above. Saturation 4.00%.

(41) 1782' Rec. 1½" same as above. Saturation 10.25%.

(42) 1787' Rec. 1½" same as above. Saturation 17.00%.

(43) 1792' Rec. 1" gray, soft, clean, porous, medium sand. No odor, taste, or fluorescence. Saturation 0.

HOMCO SIDEWALL CORES:

(12) 1736' Rec. 5½" firm green shale. No show.

(11) 1742' Rec. 1½" soft, fine to medium grained gray sand. Good oil odor, taste and stain.

(10) 1746' Rec. 1" soft, fine to medium grain, gray sand. Good oil odor, taste and stain.

(9) 1755' Rec. 3½" soft, fine to medium grained gray sand. Good oil odor, taste and stain.

(8) 1757' No recovery.

(7) 1760' No recovery.

(6) 1770' Rec. 5" soft, medium to coarse grain, gray sand. Good oil odor, taste and stain.

(5) 1774' Rec. 3" soft, medium to fine grain gray sand. Good oil odor and taste; sand is oil stained.

(4) 1779' No recovery.

(3) 1783' Rec. 3" soft, fine, gray sand. Good oil odor, taste.

(2) 1793' Rec. 5"-2½" soft fine-grained sand. No odor, brackish taste; 2½" firm green shale containing pebbles.

(1) 1790' Rec. 2" soft, fine, gray sand. Good oil odor, taste.

into either of the 4-in. 6000 psi test mud lines can be effected by the use of a quick-opening valve.

The well control equipment on Block 32 was nominal 12-in. API Series 900, 6000 psi test. One pressure operated master gate and one ram-type blowout preventer were used below another blowout preventer having a rubber pack-off unit that sealed off the drill pipe, kelly, tubing, wire lines, and open hole.

Mud conditioning equipment consists of a vibrating screen shaker and 170 bbl. sand trap located on the platform and two 250 bbl, 5 ft wide 48 ft long by 7 ft deep V-bottom active mud pits and a 400 bbl mud storage compartment in the barge hull. Complete facilities for chemical addition, mud mixing and conditioning were incorporated in the barge.

Commencement of rotary operations began on Block 32 when rigging up of rotary tools started on September 2, 1947. The well was spudded through 24 in. driven conductor pipe on September 9, 1947 and 373 ft of 20 in. OD surface casing was set and cemented with 400 sacks of regular cement on September 17, 1947 at a total depth of 422 ft. Drilling commenced below 20 in. surface casing on September 29 and proceeded until October 2, when oil shows were found at 1594 ft. Drilling was continued to 1743 ft at which point hole was reamed to 17 in. and 13⅜ in., 61 lb J-55 casing was run and cemented with 750 sacks of regular cement on October 8. Temperature surveys were run and top of the cement was determined to be at 1425 ft.

On October 12, drilling and coring was resumed below the 13⅜-in. casing and the hole was carried to a total depth of 2563 ft in salt. Conventional, wire line, and numerous side wall cores were taken in the course of drilling the Block 32 well. Figure 6 lists the cores taken and, in addition, shows an electric log of the hole. Three cement plugs were spotted in the hole; 90 sacks from 2275 ft to 2400 ft, 2050 ft to 2150 ft 70 sacks and 1834 ft to 1950 ft 250 sacks and 9⅝-in. liner was then run from 1702 ft to 1846 ft and cemented with 85 sacks of regular cement on October 23.

On October 27, casing was perforated with eight holes at 1780 ft to 1781 ft, 5 ft above the indicated water level and drill stem test taken. The recovery was 900 ft of oil and sand. The sand body was then squeezed through these perforations. Casing was perforated again at 1528 ft to 1530 ft and 1287 sacks of cement were placed at the base of the 13⅜-in. casing in five different stages.

On November 3 casing was perforated with 280 shots from 1734 ft to 1750 ft, 234 ft below the top of the first oil zone and flowing tests were conducted through 4½-in. drill pipe until November 9, when 2⅞-in. OD tubing and packer were run. On November 17. on a ½-in. choke with tubing pressure of 70 psi, casing pressure of 200 psi, the well was flowed for a number of hours at a rate of about 40 bbl per hr. Testing was then continued until November 27 when well was completed as a flowing well.

Rotary operations were terminated on November 28, 1947, after 87 elapsed

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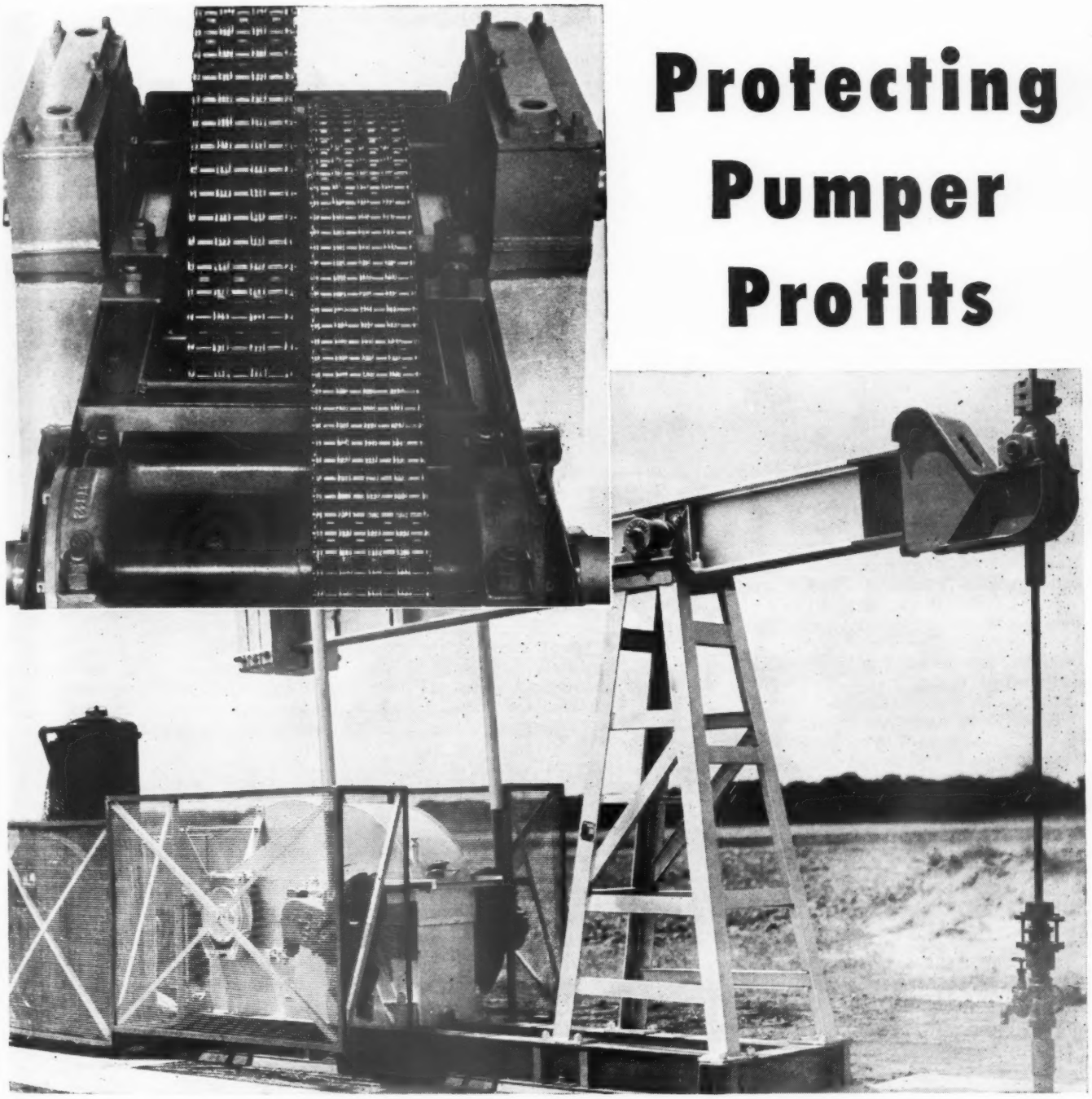

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DIAMOND ROLLER CHAINS

days of continuous operation. Of this total time, it was necessary to suspend operations 6⅓ days due to inability to keep the barge moored in working position. This represented 9.5 per cent of the time the barge was at the location, or an efficiency of 90.5 per cent, insofar as weather affects barge drilling.

This same rotary drilling equipment was used to drill the well on Block 28, with the exception of some additions made to the rig. A heavier derrick was installed on this proposed 12,000 ft well, this being a specially designed 952,000-lb capacity, 140 ft by 30 ft base derrick, with a wind load rating of 125 mph without guys. The substructure used in this case has a nominal height 16 ft by 30 ft base, 6-post, 6-truss, 1,500,000-lb unit with a two-post, truss-type engine and hoist substructure similar to Block 32.

A third diesel engine was compounded with the other two drawworks engines, giving a total hoisting power of 1140 brake hp. This was sufficient hoisting power to give "stand-a-minute" rig performance with 4½-in. pipe at 14,400 ft.

Two additional 12-in. API Series 900 Ram-Type blowout preventers were added, making a total of five pressure-operated units for well control. An air-powered hydraulic pumping unit, capable of operating pressures as high as 6000 psi, was installed to assure quick and positive closing of all hydraulically operated well control units.

The drilling barge was moved from Block 32 to Block 28 with no change in the rotary drilling installations.

Fig. 7 is a curve showing drilling progress on Block 28 and also including a record of bits and deviation of the hole from vertical.

During the drilling of the well no abnormal conditions have been encountered. Mud weight has been maintained in the range of 10.0 to 10.8 lb per gal and funnel viscosity about 38 sec per qt. Chemical treatment consists of the addition of sodium tannate, lime and soda ash to convert the system to a "Red Lime" mud and starch was added to effect water loss reduction.

Considerable difficulty was experienced in maintaining a straight hole from about 4000 ft to 6000 ft as shown graphically in Fig. 7.

On March 29, drilling was proceeding at 9737 ft, 150 days since commencement of operations. Of this total elapsed time, it is notable that seven days were lost due to adverse water or weather conditions, indicating an operating efficiency of 95.3 per cent for the floating barge method of drilling.

Transportation of personnel, supplies, equipment, and operating materials is effected by a fleet of small craft, largely comprised of war-surplus vessels. Three 85-ft air-sea rescue boats of the type shown in Fig. 8 are maintained in the service of handling personnel and light supplies, while two LCT (landing craft, tank), 180 ton, 120-ft power barges are used to handle equipment and carry heavy supplies, diesel fuel, and fresh water for drilling. The services of a tug boat have been required from time to time, usually in connection with moving the drilling barge. Fig. 9 is a low angle aerial view of the drilling barge, platform, and one of the 85 ft crew boats. One of these boats is kept standing by at the location at all times.

All boats, the barge, the platforms, and the Berwick operating office are equipped with short-range, FM two-way radios. Marine radio telephone (ship to shore) is installed on the drilling barge and one of the 85-ft boats. Any telephone in the United States can be reached by calling the marine operator at New Orleans or Galveston.

The land base of operations is at Berwick, Louisiana, on the Atchafalaya River, 52 miles from the drilling wells.

The rotary equipment is manned by four six-man drilling crews. Two crews stay out for seven days, working 12-hr tours, and come ashore for seven days when relieved by the other crews. Other full-time drilling personnel includes two tool-pushers, a mud engineer, a mechanic and welder, all supervised by the drilling superintendent. A geologist stays on board the drilling barge during the time that his services are required.

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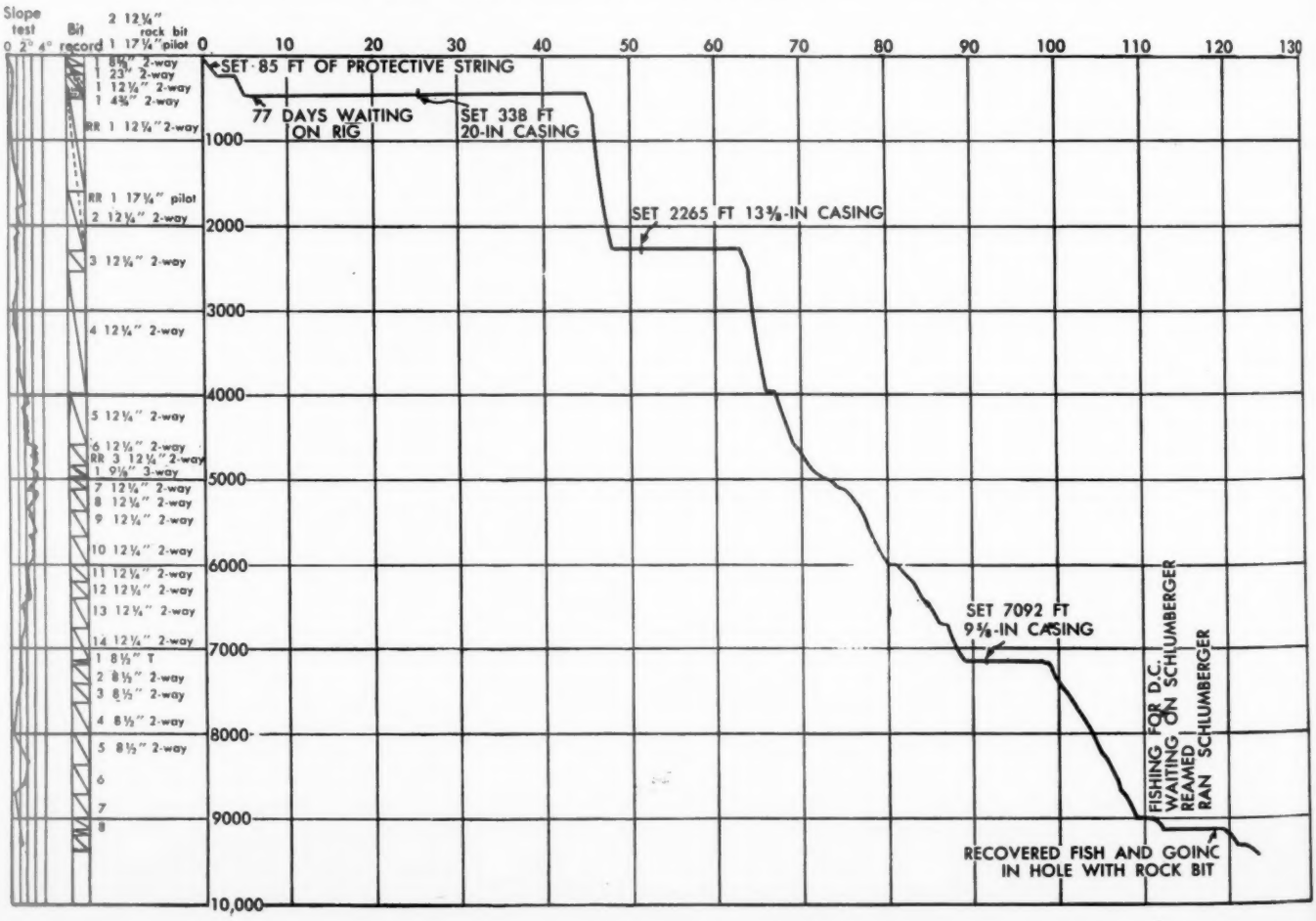
FIG. 7. Chart showing deviation, bit records, and drilling time on Block 28 well, Gulf of Mexico.



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with a compact No. 500 Drive

Oilwell's" No. 500 Dual-Engine Drive is a compact ower unit consisting of two internal-combustion ngines, extension shaft assemblies, and selective com-ounding mechanism for driving the draw works and he power slush pump.

All parts are mounted on one structural steel skid ase. The extension drive shafts are connected to the ngines by "Airflex" disconnecting clutches which act s flexible couplings. The two drive shafts are heat-reated alloy steel, supported at two points by heavy-uty, self-aligning roller bearings mounted in grease ubricated, dust-proof, cast-steel housings.

Three double-disc friction clutches are used in the ompounding assembly: (1) compound to draw orks, (2) compound to slush pump drive pulley and 3) engine to engine. Engine throttles, master-com-ound to draw works, compound to slush pump, and ngine to engine clutches are remote-controlled from he driller's position.

Roller chains and sprockets are spray-lubricated nd enclosed in oiltight, weather-roof guards equipped with oil-level auge, oil-filler cap, and drain plug. ll bearings in the shaft assemblies nd clutch remote control system are rease-lubricated.

Contact your nearest "Oilwell" representative for complete specifications on the No. 4-B Mechanical Rig and its recommended companion equipment.

with a high-volume capacity Pump

The "Oilwell" No. 14P-HD Duplex Power Pump is designed for an extremely wide range of service applications. It has a one-piece, direct-flow type, semi-steel fluid end with a rated working pressure of 2500 p.s.i.

Large, streamlined passages assure minimum restriction to mud flow. This pump is equipped throughout with heavy-duty roller bearings, the power end is lubricated by a combination oilbath and positive-flow lubrication system. The crosshead-pin roller bearings, diaphram stuffing boxes, and fluid-end stuffing boxes are pressure grease-lubricated.

Exclusive features include (1) DI-HARD fluid-cylinder liners, (2) HI-HARD piston rods, (3) TELL-TALE liner packing, (4) "HD" liner spaces, (5) alloy-steel fluid valves and seats, (6) flexible mud-baffle discs and (7) grease-lubricated stuffing boxes.

the following equipment designed for corresponding drilling depths

"Oilwell" 66-inch Streamlined Traveling Block. "Oilwell" 200-ton Swivel (No. 100-C). "Oilwell" No. RT-1717C Rotary Drilling Unit or No. 17½-A Oilbath Rotary . . . and remember "Oilwell" is a good place to buy all your supplies including: American Tiger Brand Wire Lines · National Tube Company, Tubular Goods · Thermoid Suction, Discharge and Rotary Hose.

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"OILWELL"

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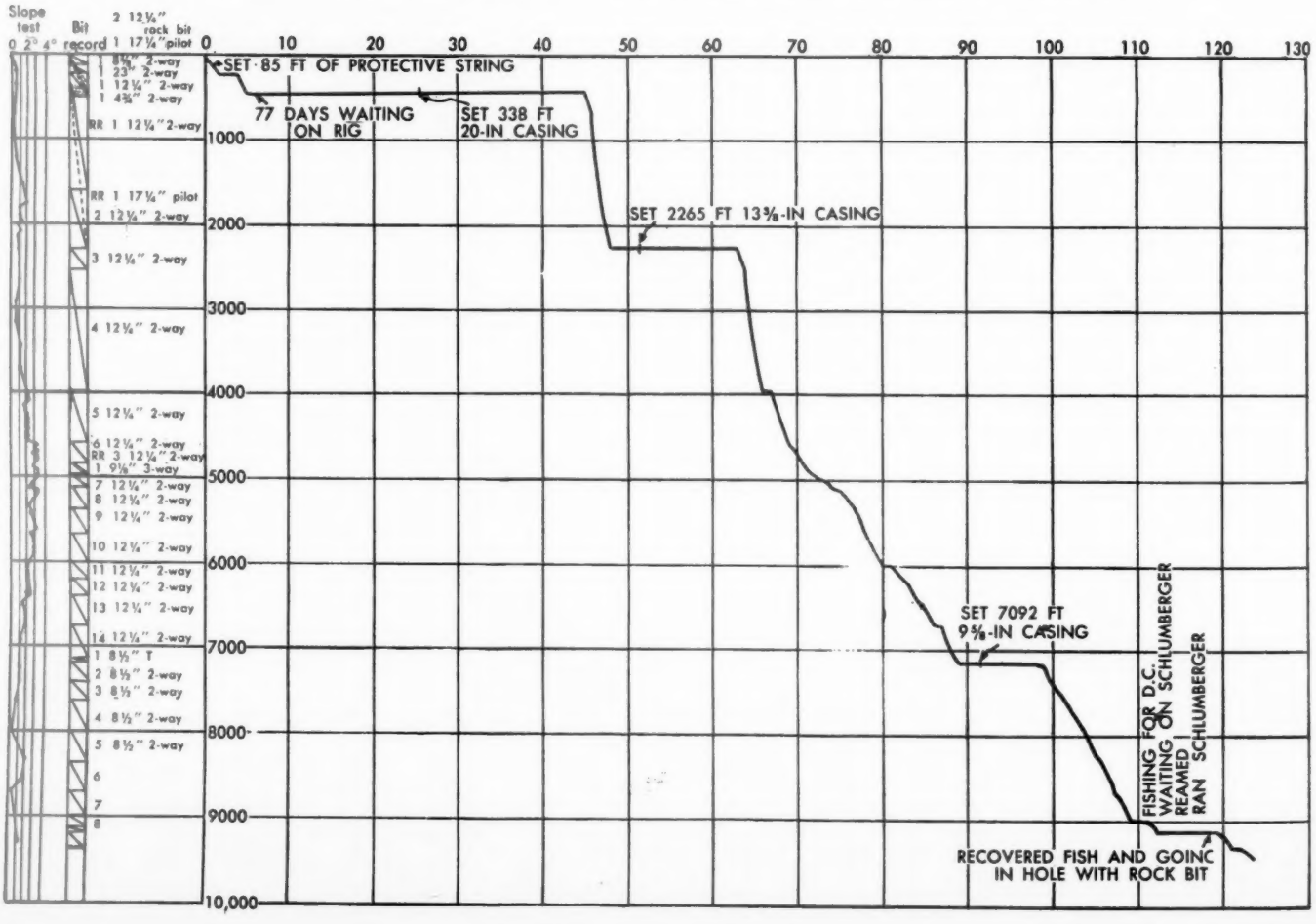

Rig with 128-A Portable Derrick

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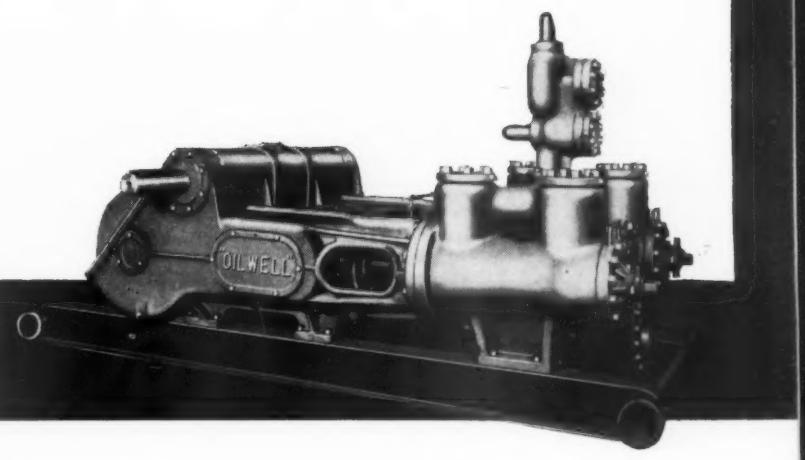

with a compact No. 500 Drive

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Three double-disc friction clutches are used in the compounding assembly: (1) compound to draw works, (2) compound to slush pump drive pulley and (3) engine to engine. Engine throttles, master-compound to draw works, compound to slush pump, and engine to engine clutches are remote-controlled from the driller's position.

Roller chains and sprockets are spray-lubricated and enclosed in oiltight, weatherproof guards equipped with oil-level gauge, oil-filler cap, and drain plug. All bearings in the shaft assemblies and clutch remote control system are grease-lubricated.

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Exclusive features include (1) DI-HARD fluid-cylinder liners, (2) HI-HARD piston rods, (3) TELL-TALE liner packing, (4) "HD" liner spaces, (5) alloy-steel fluid valves and seats, (6) flexible mud-baffle discs and (7) grease-lubricated stuffing boxes.

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gineer while the LCT craft are under the command of a captain with an engineer and two deck hands as crew members. The crews necessary to operating the electric logging, side-wall coring, and cementing equipment are transported to the location as needed. The supervisory personnel consists of a chief engineer who is in over-all charge of the operation, a production engineer, a drilling superintendent, a marine superintendent, a communications superintendent, a shore installation coordinator of activities, and a steward in charge of procuring food and feeding the personnel.

The Block 32 No. 1 well is producing from formations that appear to be of post-Miocene age and that may be as young as Pleistocene. The total effective saturated sand thickness is 180 ft. The sand is very soft and unconsolidated in character. The porosity averages about 30 per cent. In places the permeability exceeds 20,000 millidarcys. Much difficulty was encountered in completing the well because of the soft, unconsolidated nature of the sand. The well would sand-up immediately when opened. It was found necessary to bring the well in on low rates of flow during which, at times, the sand content was as high as 25 to 30 per cent. After the well had been flowed for a few days at low rates, the formation appeared to partially stabilize and the rates of flow could be increased.

When the well was flowing at the rate of 40 bbl per hr, 40 cu ft of gas was being produced with each barrel of oil. This low gas/oil ratio may be partially explained by the fact that the section of sand being produced was 285 ft below the first oil saturation in the sand zone.

The oil is 25.3° API gravity, green in color, sweet and of a naphthenic base. The well was tested into a 3000-bbl liquid cargo barge anchored alongside the larger drilling barge. Some of the equipment used in drilling and testing the well is shown in Fig. 10. In this photograph can be seen the 3000-bbl barge on which was mounted complete well testing unit, including a small separator and oil flow meter.

Following a hearing before the Louisiana State Conservation Commissioner, an allowable of 400 bbl per day for a period of six months from January 1, 1948 was granted the Block 32 discovery well. To date approximately 4000 bbl of oil have been produced since it has been impossible to find a shallow draft barge or other vessel which can be converted into a small tanker which will meet U. S. Coast Guard requirements for use in the open waters of the Gulf of Mexico. It is planned to eventually lay a marine pipe line from the Block 32 well to a point on the deep channel of the Atchafalaya River, a distance of approximately 25 miles. The construction of this pipe line has been delayed pending further production tests on the Block 32 No. 1 well and pending the drilling of additional wells to further confirm the presence of a substantial reserve of oil and gas. Acquired for this line is $6\frac{5}{8}$-in. OD, 25 lb line pipe.

The laying of the line offers numerous problems. The Block 32 discovery is lo-

FIG. 8. One of the converted 85-ft air rescue craft used as a crew boat.

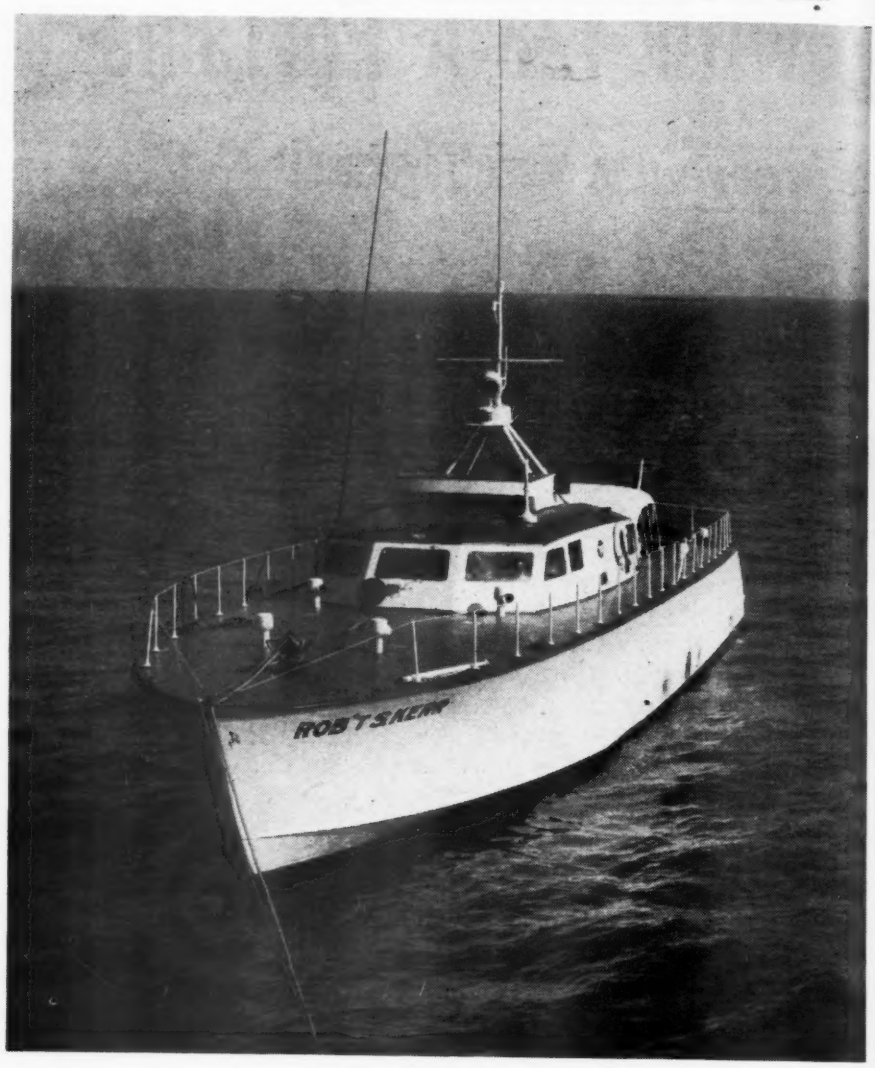
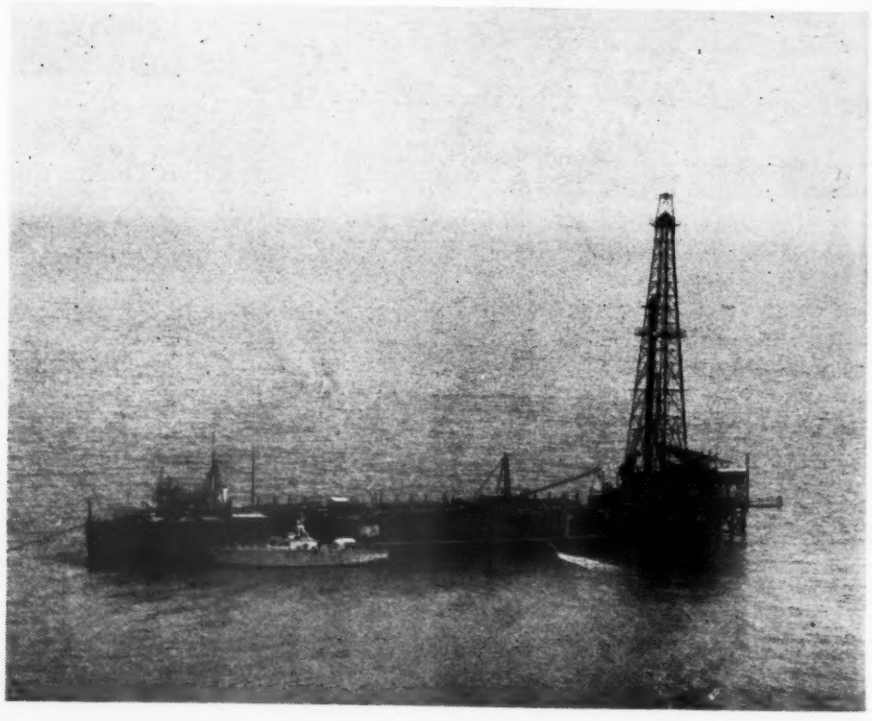


FIG. 9. Low angle aerial photo of Block 32 showing platform, drilling barge, and a crew boat.



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Cameron's Safety Xmas Trees, long the standard of comparison, are now available fabricated entirely from stainless steel units. Typical of Cameron pioneering in the field of well heads is the forged steel tubing head shown in the assembly at left. To forge a flanged tubing head of this kind from any steel alloy presents complex problems, but to forge one from stainless steel, which requires extremely precise control of metal temperature during the forging operation, is doubly difficult. Forged stainless steel well heads are not available from any other source.

Operators who are concerned with corrosive well conditions are invited to call on the nearest Cameron representative, or write for complete details on Cameron Stainless Steel Xmas Trees.

The above Xmas Tree Assembly is All-Cameron and All-Stainless Steel. It features a Cameron Type "F" Forged Steel Tubing Head, Flow Tee and Type "D" Flow Wing. See your Composite Catalog for complete mechanical details and specifications, or literature will gladly be sent on request.

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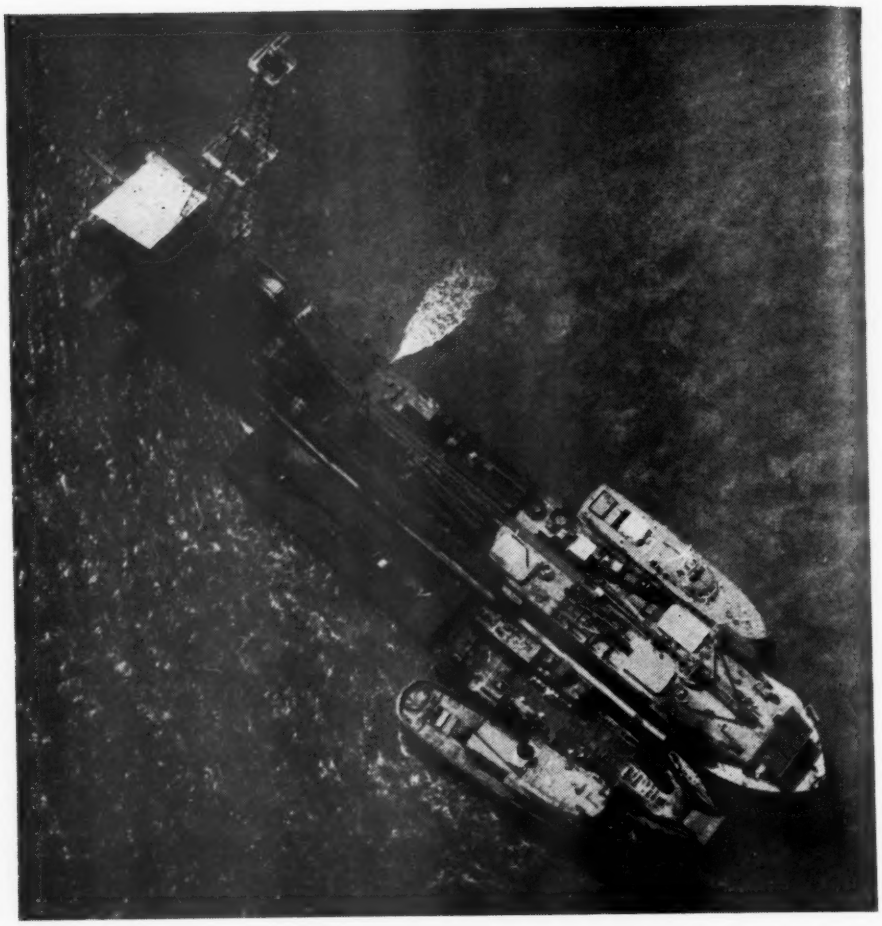
FIG. 10. Aerial photograph of Block 32 well when production tests were in progress, showing platform, drilling barge, 85-ft crew boat, 120-ft LCT tug, and 3000-bbl oil barge.



cated in the midst of some of the best shrimping and fishing grounds along the Louisiana coast. It will be necessary to bury the line approximately 6 ft below the ocean bed to amply protect it from the anchors and nets of the numerous fishing boats which work this area. At the land terminal of the pipe line it is planned to provide storage tanks, boat loading slips, and housing for the production personnel.

Since the royalty ownership under the entire block of 20,000 acres is common, the oil will be metered at each individual well in the ocean and the total production will be checked in the storage tanks at the barge terminal.

It is planned to attempt the drilling of a directional hole from the Block 32 No. 1 platform and a specially designed, compact skid-mounted rig has been built for this purpose. A deviation of 660 ft will be attempted in the first such hole drilled. If it is found possible and economic to directionally drill holes in the soft, unconsolidated formations which are present to a depth of 1800 ft, additional directional holes will be drilled from the same platform. ★ ★ ★

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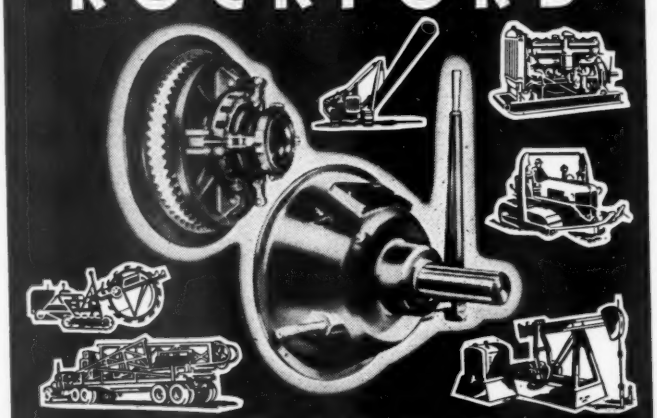

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A. ARUTUNOFF'S METHOD OF DRILLING OIL WELLS

Briefly, the new method consists in drilling by an easily transportable, rotary, electrical motor-driven unit, (50-140 ft. in length), lowered and raised in and out of the hole by a power cable. Drill pipe and mud pumps are not required. The only requirement for operation is that there be in the hole enough liquid to submerge the entire unit. Cuttings are deposited in the upper part of the unit by action of a circulating pump incorporated in the unit, which must be pulled, depending on height of the mast or derrick used, once every 10-40 ft. of hole made, to dump the cuttings.

Power cable of tapered design can be made for any depth at which oil may be expected. The motor can stand any temperature of such depths. Sluffing formation can not be missed being recognized and before the unit passes below, will be taken care of by underreaming 4″ to 5″ over the gage size, cementing and redrilling, leaving a tube of cement. Irrespective of the depth being drilled, a three man crew is sufficient.

By this new method, coring below 8,000 ft. can be done at less cost than ordinary drilling, hence it is economically feasible to core the whole length of very deep wells.

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Depth in Ft.	Price Per Ft.	Depth in Ft.	Price Per Ft.
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1,000- 2,000	12.50	11,000-12,000	33.80
2,000- 3,000	15.00	12,000-13,000	35.70
3,000- 4,000	17.50	13,000-14,000	37.60
4,000- 5,000	20.00	14,000-15,000	39.40
5,000- 6,000	22.50	15,000-16,000	41.40
6,000- 7,000	24.30	16,000-17,000	42.50
7,000- 8,000	26.20	17,000-18,000	44.30
8,000- 9,000	28.00	18,000-19,000	46.00
9,000-10,000	30.00	19,000-20,000	48.00

RIGGING UP and TEAR DOWN charge: Cost equal to 8 ft. of Core.

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Recent diamond coring in California*

By WILLIAM C HARRINGTON† and MAX C. EASTMAN‡

● **Abstract.** The use of diamond coring equipment in California has been restricted for the most part to the Stevens Zone of Paloma, Coles Levee, and Elk Hills fields. In the oil bearing hard sands of the Stevens Zone diamond coring is $8 per ft cheaper than rock bit drilling, $24 per ft cheaper than rock head coring, and the core recovery approaches 100 per cent. As the sands grade into shales the economic advantage of the diamond equipment decreases to the point where it is more expensive than rock drilling, but still cheaper than rock coring. Evidence is presented to show that diamond equipment gives very poor performance in soft shales, and has cut slower than rock core heads in soft sands.

Several attempts have been made to core formations other than the Stevens, but none of them was sufficiently sustained to provide conclusive data. Attempts to core hard schists and basalts failed, presumably due to the partially fractured nature of the rock cored.

Considerable detail is given on equipment preferences and operational practices of California operators.

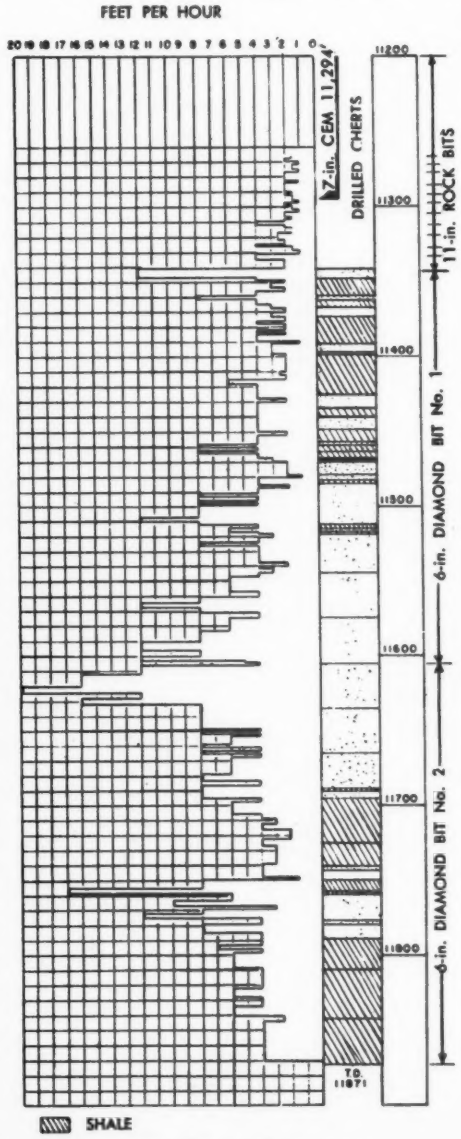
● **Introduction.** Diamond head coring equipment has been used successfully in several industries for many years, but only recently has it received extensive use in the oil industry. In the early stages of oil field rotary drilling small diameter diamond cores were occasionally taken for geological purposes. The core heads were expensive, and since the devlopment of roller type core heads, it has usually been possible to obtain sufficient recovery at much less cost. However, diamond coring equipment continued to be used infrequently in attempts to increase recovery or rate of penetration; meanwhile, the mining industry improved the coring equipment, particularly the methods of setting the diamonds in the bit.[1]

The possibilities of increased speed and increased core recovery led to the use of diamond bits at Rangely field, Colorado, with outstanding attainment of both possibilities.[2] The success at Rangely prompted the use of the diamond equipment in California, the first run occurring at Elk Hills, but more profitable operation of this equipment has occurred in coring hard sands at Paloma and Coles Levee fields.

● **Diamond coring in California.** More than 98 per cent of the total footage cored by use of diamonds in California has been in the Stevens Zone of Paloma, Coles Levee, and Elk Hills oil fields. This zone varies from 5150 ft to 11,600 ft in depth and consists of sediments ranging from hard cherty shales and sandstones to soft shales and loosely consolidated sands. Both fractured and massive shales occur. The wide variation in the physical characteristics of the sediments occurring in this zone has provided considerable data on the advantages and limitations of diamond coring. Several limited attempts have been made to core other formations, these attempts have either been unsuccessful or of such limited duration that the results were inconclusive.

Diamond coring equipment has been used to core the productive zone of 13 Stevens Zone wells. In 12 of the wells, 7-in. casing was set at the top of the productive zone and oil base mud was used in coring. In one well, 9⅝-in. casing was set and a 6⅜-in. diamond head was used with water base mud. Diamond coring operations are continuing in the Paloma field with the data on nine wells being included in this report. Table 1 lists the uses of diamond equipment in California from July, 1947, to about the end of February, 1948, and shows the average performance in various types of formation. Fig. 1 shows a penetration record for a Paloma well containing shales and sand. In both sands and shales the diamond head will cut faster, and permit more penetration per trip than either rock core head or rock core bit.

FIG. 1. Penetration and core record of typical well in Paloma oil field.



● **Core recovery.** In the sandstones the core recovery with diamond heads closely approaches 100 per cent, with several wells having had full recovery. Rock head core recoveries of this sand averages 75 per cent. The recovery remains high as the sand grades into massive shale, and at Elk Hills the recovery of massive shale was 93 per cent. However, the shale is often fractured and slickensided and in such material the core recovery dropped to 27 per cent in a zone that was sufficiently fractured to have an initial production of 150 bbl per day. High recoveries are generally obtained of massive intercalations of hard sands and shales, whereas in rock head coring the sand stringers are most often lost. Poor recovery was obtained in one well, however, where hard shales were intercalated with soft sands.

The shales, especially when fractured, tend to jam in the core barrels, reducing the number of feet per trip. The Stevens shale, however, is sufficiently soft so that the diamond head will cut up lost recoveries without major damage to itself, although with noticeably increased wear.

● **Limitations of diamond coring equipment.** It has been shown that optimum results have been achieved in the coring of hard sands and that the diamond equipment will cut associated shales with somewhat less economic advantage. Several other trials of the equipment have further defined the limits of its present usefulness, however.

1. Circulation rate. The necessity of low circulation imposes some mechanical limitations on the use of the equipment.

In one well with open 12½-in. hole above the 6⅜-in. diamond cored rat hole, it was found that the cuttings were not being carried to the surface by the water base mud used and it was necessary to run a 12¼-in. bit to remove the cuttings. In this case, however, the recovery was very low and the amount of cuttings was greater than normally expected.

2. Soft formations. In soft formations it has been found that the diamond core

*Presented before the Spring Meeting of the Pacific Coast District, Division of Production, American Petroleum Institute, Biltmore Hotel, Los Angeles, California, May 6-7, 1948.

†Standard Oil Company of California, Taft, California.

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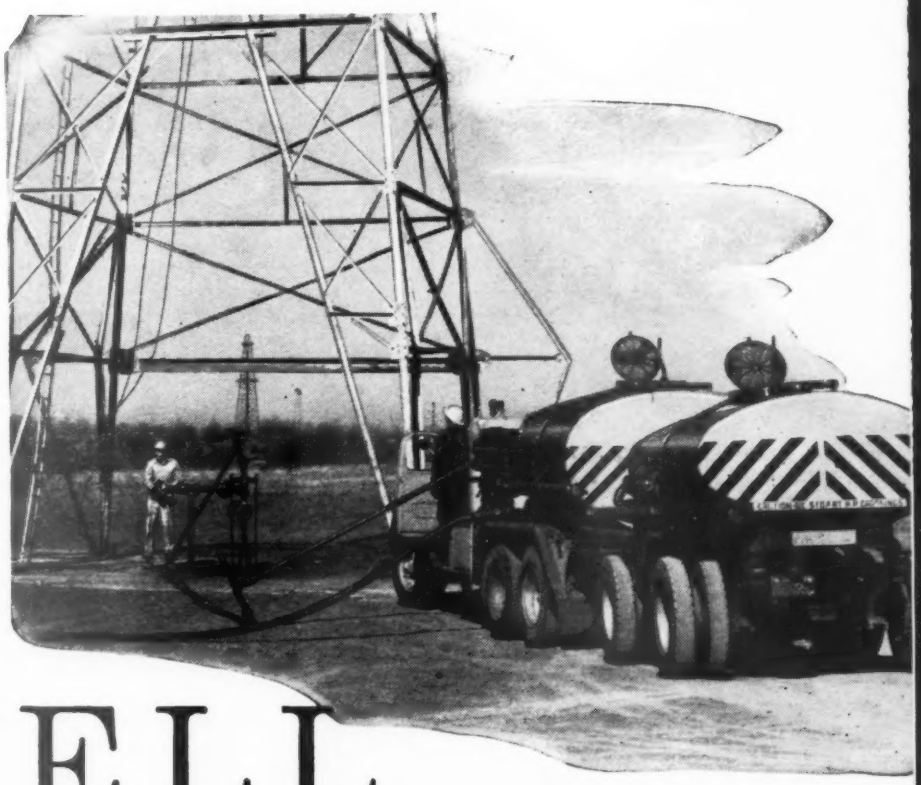

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KANSAS EXAMPLE:

Wells completed in the Arbuckle formation many times produce water with the oil after conventional acidizing. Dowell was called to treat a new well making 24 bbl. of oil per day. After considering all factors involved, the Dowell engineer carefully stage-treated the well allowing time for adequate testing between stages. Production increased to 288 bbl. of oil per day with no *water.*

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head does not perform as well as rock head equipment. In two wells where the sand was very soft the diamond bit was followed by a rock core head, as follows:

Well A—Diamond head cut 32 ft in 18.4 hr, or 1.75 ft per hr, followed by rock core head which cut 17 ft in 6¾ hr, or 2.5 ft per hr.

Well B—Diamond head cut 32 ft in 13½ hr, or 2.4 ft per hr, followed by rock core head which cut 30 ft in 8 hr, or 3.75 ft per hr.

In both cases, however, the crews were inexperienced in using the diamond bit.

Two attempts have also been made to core soft shales, one attempt in the Stevens Zone in western Elk Hills, and one attempt at Del Valle. In the Elk Hills well the core head cut 7 ft at a rate of 1 ft per hr, with a recovery of 6 ft. High torques were observed during cutting. A rock bit cut at a rate of 3.55 ft per hr prior to the diamond core, and a rock core head cut at 2.37 ft per hr following the diamond head. At Del Valle a 6-in. diamond bit cut 3 ft at a rate of 1.5 per hr, and was followed with a rock core head which cut at a rate of 4.25 ft per hr. Drilling rate in this zone was 6.0 ft per hr.

In these runs in soft formation the diamond heads were not damaged, and no increase in the amount of wear could be observed.

3. *Hard formations.* The hardest massive formations on which the diamond has been used are the silicous shales with stringers of chert that are present in the Stevens Zone. It has been shown that these can be cut satisfactorily, but with somewhat less advantage than obtained in coring the sands.

Attempts have been made to use the diamond core bit in basalt and schist, both of which normally drill slower than the shales. Unfortunately, in each case the first bit ran was damaged by mechanical trouble. The 8½-in. rock bits run ahead of the diamond head in the schist averaged 8 to 9 ft per trip. The

TABLE 1. Use of diamond coring equipment in California.

Area	Rock type	No. wells	Feet cored	Feet per hr	Feet per trip	Per cent core recovery
Paloma	Predominately hard oil sand, some shale	4	1863	4.83	27.6	88
Paloma	Shale, sandstone, and oil sand	5	2630	3.2	24.6	85
Coles Levee	Predominately hard oil sand	1	863	3.8	23.2	100
Coles Levee	Sand and fractured shale	1	186	6.25	25.6	84
Coles Levee	Predominately oil sand	1	294	2.34	26.7	90
Elk Hills	Shale, with zone of fracturing	1	456	2.0	21	58
Elk Hills	Shale and friable sand	1	122	1.3	30	30
Elk Hills	Soft shale	1	7	1.0	7	86
Mountain View	Quartz veined schist	1	6	0.54	2	53
Chico	Basalt, some fracturing	1	5	0.46	2.5	90
El Toro	Basement	1	30			
Del Valle	Soft shale	1	3	1.5	3	83
Long Beach	Information not available at this time.					

TABLE 2. Cost of representative diamond bits.

Type formation	Size bit, in.	Carats	Costs	Credit	Net cost	Feet cored	Bit cost per ft	Comments
Shale	6⅛	499.05	$3,793.35	$ 515.20	$3,278.15	205	$15.99	Bit ruined by iron.
Shale	6⅛	366.65	2,866.55	1,585.50	1,281.05	80	16.01	Returned before breakdown.
Sand	6	271.90	2,203.30	612.15	1,591.15	320	4.98	Ran too long; periphera failure.
Sand	6	289.70	2,327.90	1,318.50	1,009.40	543	2.10	Returned before breakdown.

6⅛-in. diamond bit, with large diamonds, cut the schist at slightly less than 1 ft per hr, slowing up toward the end. It was not possible to keep the pump pressure below 500-600 psi, and the bit was lifted off bottom several times in attempts to reduce the pressure. The core recovered consisted of dense schist with quartz veins, and was partially fractured. The diamond head was worn out. In this case it is probable that the excessive bit wear may have been caused by running on hard, loose fragments of core that dropped out of the head as the pressures were being checked. As a matter of interest one of the larger pieces recovered was cut with a ¾-in. OD laboratory diamond plug cutter at the rate of ½ in. per min.

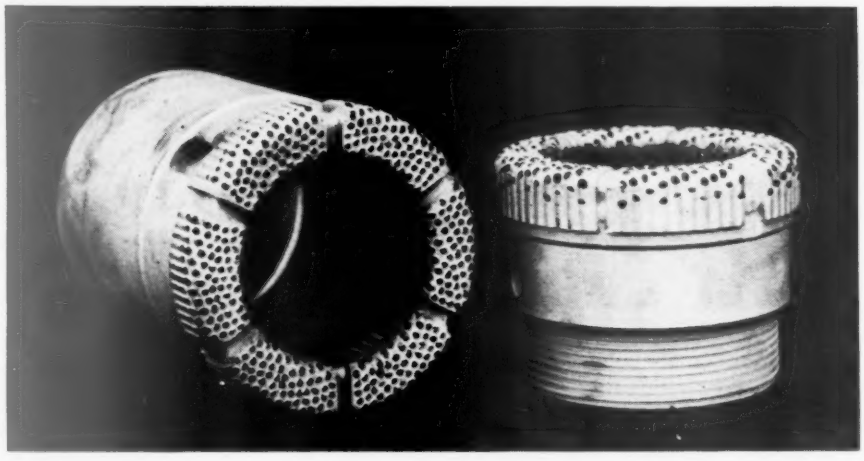
At Chico rock bits averaged 7 ft per bit in the basalt. Following the rock bits an 8¾-in. diamond bit reamed 76 ft, of hole in 15 hr without reaching bottom. In a second trial an 8¾-in. bit with 337 carats of ⅜ to ½ carat diamond, run at 80 rpm, cut 5 ft at 0.46 ft per hr with 4½ ft recovery in two trips. The diamonds on the bit were worn down smooth with the matrix. The formation recovered was hard basalt, with a weak high angle fracture system. From these two experiences it appears that very hard rocks, particularly if fractured, may not core successfully with the present diamond oil well equipment, even though massive specimens of the same rocks may be diamond cored by mining or laboratory equipment.

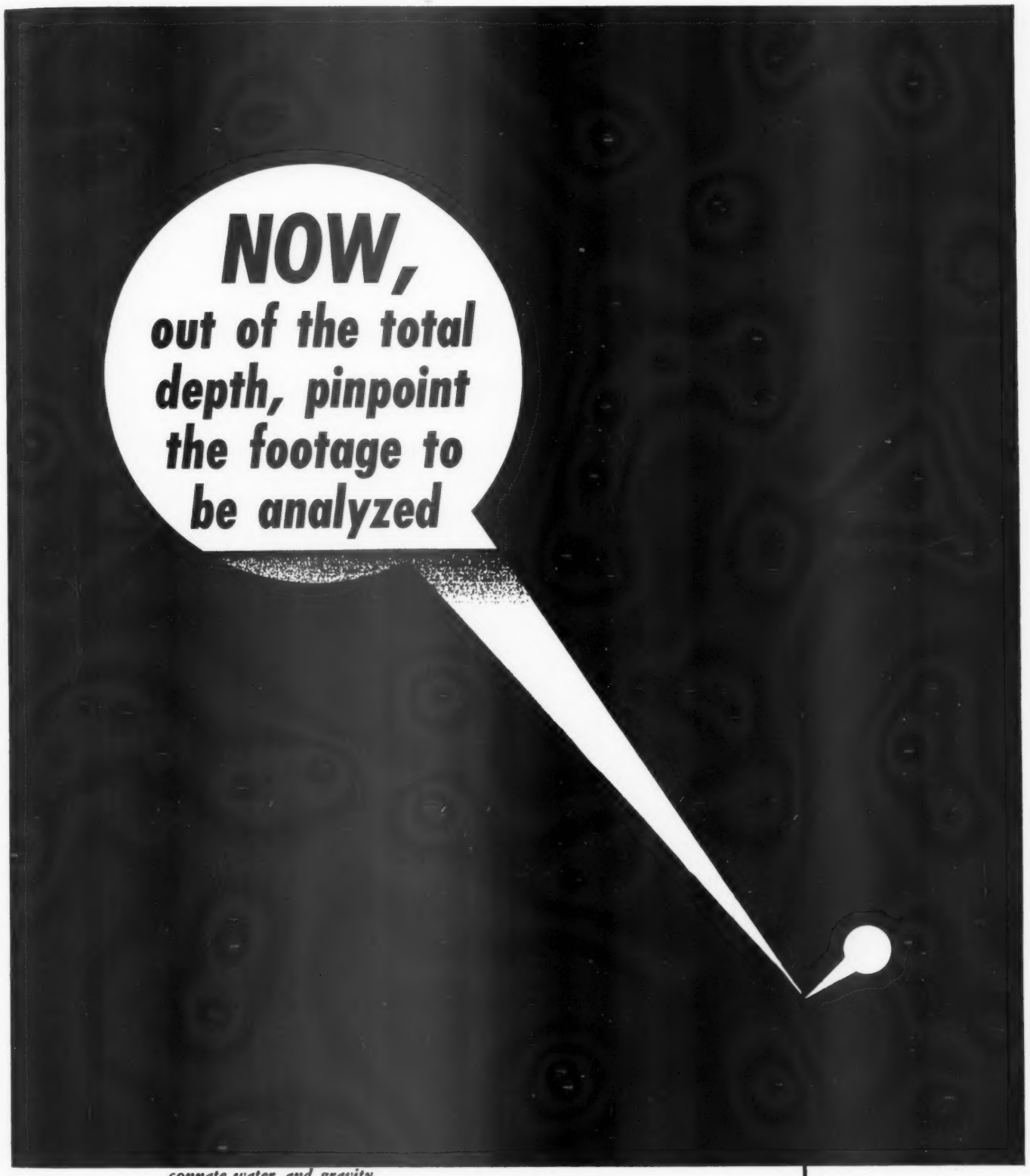
● **Equipment.** The equipment used in California is of the same type as that used at Rangely[2], and consists of a diamond core head (Fig. 2), split ring tapered core catcher, and sectioned double tube core barrel, in which the inner barrel is hung on a bearing at the upper end.

1. *The diamond bit.* Fig. 2 illustrates the type of head currently used at Paloma field. The maximum penetration with such a bit in California has been 600 ft in sandy sections. The head design has had several modifications, particularly in the shape of the bottom surface of the bit, in the number of watercourses, and in the size, type, and location of the diamonds. The heads with a flat bottom surface, as illustrated, have been most satisfactory, as the even wear of the diamonds on the flat bottom face gives maximum diamond life. Three heads with rounded bottom surface have been used at Paloma and cut faster than flat bottom heads, but uneven diamond wear resulted in an increase in diamond cost per foot drilled.

It will be noted that the bits illustrated have six circulation courses. This design is satisfactory for oil base mud. When this type bit was used to core shales in water base mud, however, excessive erosion and damaging of the diamonds occurred on the downstream side of the watercourses. Better results were obtained using bits without circulation courses on the bottom surface, but with two shallow courses on both gauge cut-

FIG. 2. Diamond core heads, 6 in. by 3¾ in., used at Paloma field. Left, with inside threads, bit contains 237.55 carats of 1/3 to 1/2 carat stones. Right, with outside threads, bit contains 337.10 carats of ¾ to 1 carat stones.





connate water, and gravity.

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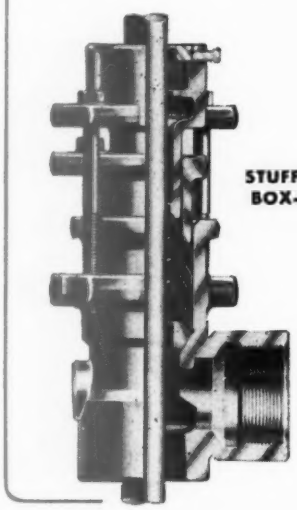

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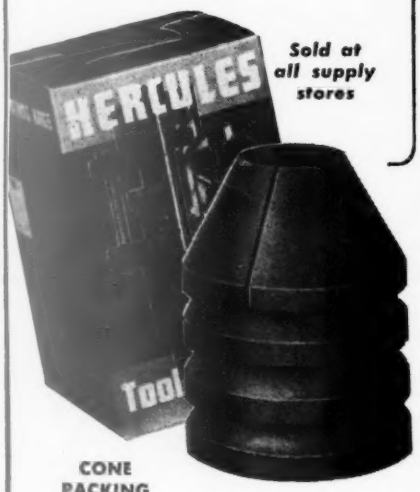

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TABLE 3. Operating conditions using diamond equipment.

Mud type	Oil base	Water base
Mud characteristics...	76-87 lb, 95-145 secs. visc.	85 lb, 55 secs. visc
RPM	90–160	80–200
Weight, lb.	4000–6000	1000–4000
Pump pressure, psi...	650–850	250–350

ting surfaces. A maximum footage of 205 ft was obtained with this type bit in hard shale.

Best results have been obtained using "large" Congo diamonds of about 1 carat weight. Smaller size stones cut effectively but the bit has a shorter life because less erosion of the matrix is required to cause loss of diamonds. It has been observed that the dull black diamonds have a tendency to fracture and the light colored glassy stones show the least wear.

It has been noted that the diamonds on the inner and outer reaming surfaces often show the most wear, limiting the life of the bit. Much of the wear on the outer diamonds is ascribed to chipping of the diamonds on the casing joints during trips in and out of the hole. An attempt to reduce this loss by reducing the number of diamonds on the reaming surfaces was unsuccessful, as the fewer diamonds wore out faster, further shortening the life of the bit.

Bits of the same nominal size will have some very small variations in diameter depending on the size of stones used and the amount of wear of the stones on the outer reaming edge. This variation in size is sufficient to be of significance as is detailed hereafter under "Operations."

The practice of California operators is to return the bits for salvage when the diamonds on some surfaces show such wear or erosion that an additional run may cause bit failure. Failure of any surface results in excessive diamond losses. Cost detail on the two 6-in. bits in Table 2 show that about $600 additional diamond cost was incurred by inadvertently running one bit to failure.

There is not sufficient data available to determine the effect of bit size on performance. Six-inch OD core heads were used at Paloma and Coles Levee, 6⅛-in. heads at Edison, 6⅜-in. heads at Elk Hills, and 8¾-in. heads at Rio Vista. Both 6-in. and 6⅜-in. core heads have a core diameter of 3¾-in. The additional cutting surface of the 6⅜-in. bit requires additional diamonds and increases the bit cost as shown in Table 2.

The bit failures that have occurred in California have all been ascribed to undersized hole, iron in the hole or excessive wear, with none of the failures believed due to faulty bit construction.

2. *The core catcher.* The split ring core catcher is considered to be satisfactory in massive formations where high recovery is obtained. It is fairly common, however, to obtain partial recovery and pick up the remainder of the core on the next run. It is probable that excessive wear of the catcher is responsible for failure to pick the core off bottom.

Several mechanical failures of the core catcher have occurred with broken pieces of catcher dropping through the bit and ruining the diamonds. At Paloma this difficulty has been reduced by changing the core catcher on every run. The used core catchers are magnafluxed at a cost of 50 cents per catcher and inspected for wear before being rerun.

3. *The core barrel.* The sectional double tube core barrel first used had right hand threads throughout and on several occasions the inner barrel unscrewed when jammed with the core. Some trouble was also had with failure of the bearing at the top of the inner barrel. The Mercury barrel now in general use has left-hand threads below the bearing that do not unscrew in operation, and also has an improved bearing that operates satisfactorily with proper servicing.

Experience at Elk Hills, with similar occurrences in other fields, suggests that jamming of cores in the barrel is the major obstacle to the successful coring of somewhat fractured shales. Jammed cores contribute to lost recovery, cause excessive bit wear, and limit the length of core that may be taken.

In the initial operations, core barrels 50 ft in length were used at both Paloma and Elk Hills, but shorter barrels are now used in both fields. At Paloma it was found that 50 ft is too long an interval to leave the equipment on bottom without inspection, and better results are obtained by pulling 30-ft cores and inspecting the equipment at that interval. At Elk Hills it was found that in shales it was seldom possible to cut over 30 ft without plugging the barrel, so a 36-ft unjointed barrel was used after the 50-ft barrel failed in the middle collar.

● **Operation of diamond equipment.** Operation of the diamond core head has required much more attention from all concerned than does the use of roller type equipment. The expensive head is subject to abnormal wear and destruction by use of excessive speeds, weights, or pump pressures. The performance of the bit is greatly influenced by the experience and skill of the drilling personnel, it being particularly important to maintain a correct and constant weight on the bit. Table 3 gives the operating values generally used by California operators in the Stevens Zone.

TABLE 4. Comparative cost of penetrating Stevens Zone.

Average depth, ft	Rock type	Cost per foot		
		Rock head drilling	Rock head coring	Diamond coring
11,000	Predominantly hard sands	$36.00	..	$ 28.00
11,000	Cherty shales and hard sands	38.00	..	34.00
11,000	Cherty shales and hard sands	..	$ 61.00	37.00
6,600	Cherty shales	33.60	49.34	39.34

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TABLE 5. Comparative performance and costs.

Type head	Rock core head	Rock bit	Diamond head	Rock core head	Diamond head	Rock bit	Diamond head
Size head	6¾-in.	6⅜-in.	6⅜-in.	6-in.	6-in.	6-in.	6-in.
Formation	Shale	Shale	Shale	Sand and shale	Sand and shale	Sand	Sand
Feet penetrated	74	427	456	397	305	519	520
Feet per bit	9.2	19.4	87	12	152.5	17.6	260
Feet per hour	1.4	1.4	2.0	1.95	4.0	2.1	4.4
Feet per trip	9.2	18.6	21.7	12	25.4	17.6	29
Head cost per foot, incl accessories	$13.30	$ 5.30	$17.14	$11.00	$ 9.00	$ 6.00	$ 8.00
Rig time per foot	$36.04	$28.30	$22.20	$50.00	$26.00	$30.00	$20.00
Total cost per foot	$49.34	$33.60	$39.34	$61.00	$37.00	$36.00	$28.00

The use of 500-psi pump pressure and circulating rate of 135 gpm water base mud caused excessive erosion of the matrix in the head, but pump pressures to 350 psi and ciruclating rates of 80 to 100 gpm were satisfactory. The many variables involved prevent a quantitative comparison of the relative desirability of water base and oil base muds as a circulating medium while coring. However, the 6-in. diamond heads used in shale sections with oil base mud averaged considerably more footage per head than 6⅜-in. heads with more diamonds in water base mud.

As previously mentioned, diamond heads of the same nominal size may vary slightly in diameter and several diamond bits have been worn out by reaming undersized holes. Where extensive coring operations are in progress, and bits of various diamond sizes and stages of wear are available, the practice is to follow a worn bit with one of the same or smaller diameter. On less extensive operations where a series of core bits are not available the hole may be reamed with a sharp rock bit of the same or slightly larger diameter. On beginning coring operations in hard formations it is advisable to drill a pilot hole with a rock bit slightly larger than the nominal diamond bit size.

Much of the wear and most of the shock damage is generally believed to occur in the initial stages of coring, so considerable care is given to setting the diamond head on bottom and avoiding excessive weights at that time. One operator believes it desirable to remain in the hole sufficiently long to allow full expansion of the drill pipe before setting full weight on the bit. The practice is to ream the full length of the previous core, then begin coring with not more than 2000 lb weight for 20 min, gradually increasing the weight to 6000 lb.

Inasmuch as there is little tolerance between the 6-in. hole and the 5¾-in. OD stabilizer fins at the top of the core barrel, most operators run jars and safety joints with the diamond equipment. This practice appears justified as the equipment was found to be necessary on six occasions. The equipment rental fee over this period was approximately $15,000. The only fishing job of diamond equipment to this time was caused by a twistoff of the core barrel in fractured shale.

The diamond core hole is generally reamed before running a liner; however, it has been found that the hole can be reamed in about one-half the time and the reamer lasts about twice as long as in a conventionally drilled hole.

● **Costs.** The many variables in performance and cost of various types of bits can best be evaluated by comparative cost data, as presented in Tables 4 and 5.

The costs shown in Tables 4 and 5 include costs of heads and all accessories, including jar and safety joint rental, and total rig time costs. Rig time includes time spent on round trips with the head and time spent on special operations, such as reaming, junk basket coring, and extracting of cores, which are necessarily part of diamond head operations.

● **Conclusions.** It is concluded that the use of diamond coring equipment in the Stevens sand has resulted in improvement in rate of penetration, increase in core recovery, and decrease in costs. As the sands grade into shale, the economic advantage of the diamond equipment decreases to the point where it is more expensive than rock bit drilling, but still is cheaper than rock head coring. Attempts to use the diamond equipment in very hard or in soft formations have not been successful in California.

● **Acknowledgments.** The authors wish to express their appreciation to the Western Gulf Oil Company, The Ohio Oil Company, the Standard Oil Company of California, and Unit Operation, Naval Petroleum Reserve No. 1, for permission to use the data presented in this paper, and gratefully acknowledge the assistance of Glenn Kersten and J. R. Weaver of Western Gulf Oil Company, Fred Henry of The Ohio Oil Company, and the staff of UO-NPR-No. 1 in the preparation of this paper.

The opinions and conclusions expressed in this paper are those of the authors and do not necessarily represent those of the Standard Oil Company of California or the United States Navy.

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Drilling mud problems of Rocky Mountain Region*

By D. D. VARNELL and W. B. KIMBRELL, Baroid Sales Division, National Lead Company

● **Introduction.** Past experience with deep drilling in the Rocky Mountain region has proved that drilling can be done without undue hazards, if all factors are properly considered. Marked progress has been made in the development of better drilling technique, with special attention being given such items as proper drilling weight, drill pipe rotation speeds, circulating mud volumes, concentrating drilling weight by use of multiple drill collars, and hard formation bits. The improvements along these lines have invariably led to decreased drilling time and better hole condition. Headway has also been made in the control of drilling mud and through the use of planned programs. Most of the troubles caused by sloughing shale, tight hole conditions at porous sections, abrasiveness, and contamination of producing zones have been eliminated. A program coordinating the improved knowledge of drilling techniques with sound mud control has reduced drilling time and cost, given complete testing and logging information, and resulted in better well completions.

The mud problems in the Rocky Mountain region are varied and directly associated with the geological sections involved. The uppermost Jurassic and Cretaceous formations present loss of circulation problems, the Triassic and Permian formations contain anhydrite contamination, and the Pennsylvanian has low permeability sands requiring protection.

● **Jurassic and Cretaceous formations.** The Jurassic and Cretaceous formations are mostly sands and shales that drill at a fast rate and stand up very well with an average mud. There are no detrimental contaminants, and the shales supply a normal amount of satisfactory base mud. The main mud problem results from a low formation pressure coupled with a fractured and highly permeable condition, which often results in severe lost circulation trouble. The loss of circulation is not consistent and varies from slow leaks to cases where all circulation is lost, with the fluid level dropping several hundred feet down the hole. The severe losses are expensive to overcome and can result in a sizeable cost, if the problems are not attacked in a systematic manner.

The best proved procedure for combating severe losses embodies a few simple rules, and on most occasions their use has saved time and expense. While drilling expected loss circulation zones it pays to be on the alert and observe the loss as soon as possible. This will not only conserve mud, but it will prevent undue enlargement of the leaking channels. A good practice has been to keep the pump suction with as little submergence as possible, so that air enters the pump as soon as any appreciable amount of mud is lost. It is important to use a bit with large watercourse openings, so that high concentrations of lost circulation material can be pumped in without danger of plugging. Carrying lost circulation material in the mud and drilling the expected zones at a slow penetration rate often seals smaller leaks as they are penetrated. Reducing the hydrostatic head by maintaining as low a mud weight and pump pressure as possible has proved helpful.

If complete circulation is lost it is best to pull the drill pipe to a safe position and add a bentonitic material such as Aquagel to the surface mud until a high viscosity and high gel strength mud is obtained. At the same time add about 12 lb of bulk lost circulation material per barrel of mud, and then lower the drill pipe to the position of the leak. The prepared mud is then spotted in the same manner as cement on a conventional plug back job, and the drill pipe is again pulled into a safe position above the level of the high viscosity mud. After the hole has set under static conditions for 4 to 6 hr, the drill pipe is lowered to bottom and the high viscosity mud is circulated out at 200 to 300 ft intervals and thinned back to normal.

By this procedure, the full benefit of the lost circulation material is obtained by keeping it concentrated at the leaking area, and the static period permits the high gel mud to reach its maximum gel strength in the leaking channels, rendering it highly resistant to further movement.

Most of the lost circulation trouble can be overcome by this method, but there have been cases where the leaking channels were exceptionally large and required cementing. If one or two attempts with the mud procedure do not remedy the trouble, it is considered good practice to resort to cementing, using 3 to 4 per cent bentonitic material.

● **Triassic and Permian formations.** The Triassic and Permian formations are essentially sands and red shales containing interbedded anhydrite ($CaSO_4$) stringers. The anhydrite is relatively soluble and presents the major chemical treating problems in the Rocky Mountain region. The chemically active calcium sulphate has an extremely detrimental action on the mud, and its first effect is noted by a marked increase in viscosity and gel strength, which is followed by an excessive increase in filter loss. The immediate effects are twofold: First, the mud becomes highly resistant to flow, and the increased pump pressure either causes or renews lost circulation trouble formerly corrected; second, the high water loss and poor flow characteristics cause the upper shales to start caving.

The most popular method of combating the soluble anhydrite has been to pretreat with a small amount of caustic and quebracho and then add a barium carbonate compound such as Anhydrox as needed to remove the calcium sulphate in the form of insoluble barium sulphate and insoluble calcium carbonate. This treatment is simple to use and consists of maintaining a pH of 9 with caustic soda and quebracho, (avoiding a concentration of quebracho greater than one pound per barrel of mud, as greater quantities may inhibit the barium carbonate compound reaction), and adding the barium carbonate compound as needed to offset increases in viscosity. This keeps the mud in a fluid condition and maintains the filter loss at the original amount.

The second treatment employs the use of caustic soda, quebracho and soda ash (Na_2CO_3) and is applied in the same manner to form insoluble calcium carbonate and soluble sodium sulphate. The important difference in the two treatments is that soluble sodium sulphate is formed with soda ash, where insoluble barium sulphate is formed with barium carbonate. The soluble sodium sulphate is not detrimental at low concentrations, but has the same effect as salt when the concentration becomes high. This condition causes soda ash to reach a treating end point and limits its use to areas where only small amounts of anhydrite are present.

The barium carbonate compound treatment has considerable advantage in that both the treating chemical and contaminating chemicals are completely removed, leaving the original chemical make-up of the mud unchanged. Consequently, it does not reach a treating end point and can be used to treat out any amount of anhydrite. Moreover overtreatment with barium carbonate has no harmful effect.

● **Pennsylvanian formations.** The producing sands in the Pennsylvanian formations have varying permeabilities and contain fine shale particles intermixed with the sand grains. The permeability is greatly influenced by the concentration of the shale particles, and even in the better zones there appears to be a fairly large percentage of shale particles present. Past information indicates that these minute shale particles hydrate easily, and when in contact with fresh

*Presented before Petroleum Division, American Institute of Mining and Metallurgical Engineers, Denver, Colorado, September 28-October 2, 1947.

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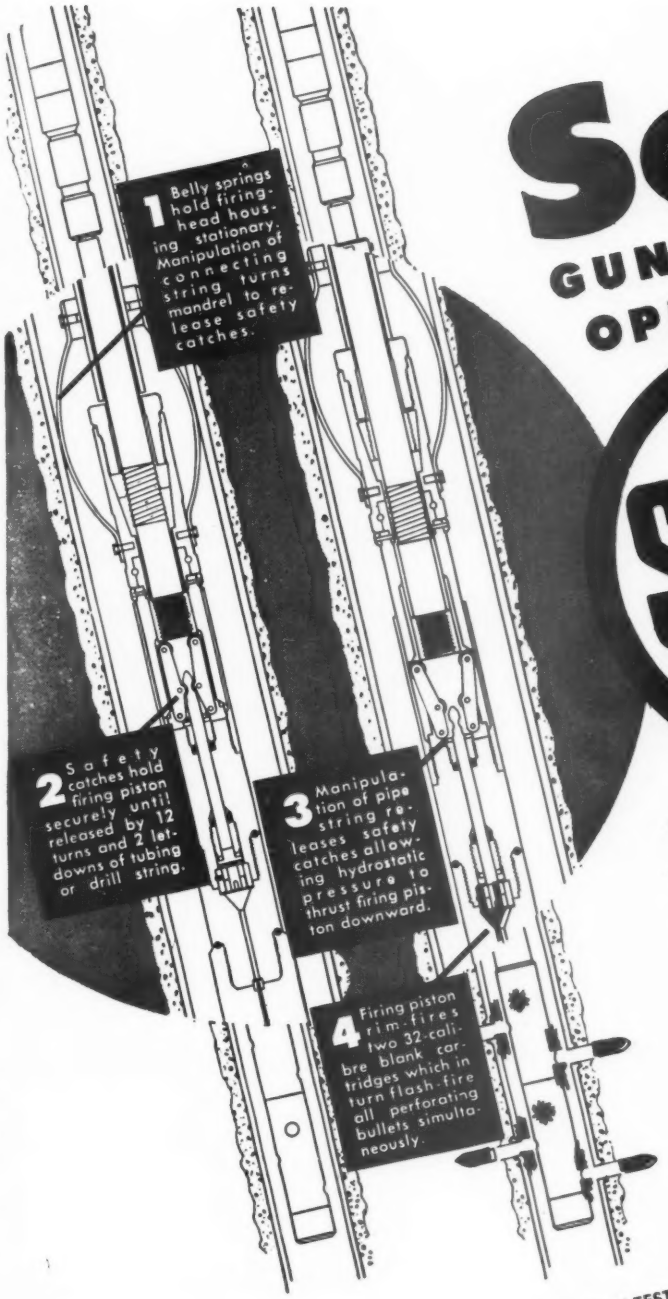
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water, increase their effective size to temporarily, or possibly permanently. reduce the permeability of these sands to the flow of oil.

In the last few years several muds have been developed with a primary purpose of overcoming this condition. Oil base muds have been used and appear to be helpful in several areas, but they are expensive and require a careful balance of cost against expected gains. The most recent consideration of the problem involves controlling the hydration of these shale particles by varying the chemical composition of the liquid phase in a water base mud.

It has been known from the beginning of mud studies, that various water soluble chemicals, when added to the liquid phase of a mud, will suppress the hydration of clay. The most noticeable one is salt water, which suppresses hydration to a point where many high yielding clays only give viscosity increases comparable to those obtained with non-hydrating particles. Therefore, adjusting the salinity of the water offers one way in which the degree of hydration can be controlled.

The shale particles associated with the sand are subjected to the connate water, or to the production water, if the well makes water initially, and have been hydrated to the maximum amount permitted by the particular type of shale and the degree of salinity of the wetting water. If a mud is used having a liquid phase of less salinity than the formation water, then the entry of filtrate into the sand may increase the degree of hydration of the shale particles resulting in a decreased permeability. The permanency of the decreased permeability will depend on the rate of displacement of the drilling water with formation water, as dehydration will not begin to take place until the shales have become wetted again with normal salinity water.

All water soluble calcium compounds have similar effects on the hydration of clays, at least at ordinary pH. Mixtures of sodium chloride and calcium chloride are also very effective, but their use has so far been limited.

A good procedure for protecting the permeability of a sand containing clay material is to measure the amount of hydration a similar shale exhibits in the formation water and use a mud having a liquid phase that causes the same shale to hydrate to a lesser amount. This should assure the shale particles remaining at their original effective size with no change in their effect on the permeability.

● **Miscellaneous mud problems.** Another mud problem common in the Rocky Mountain region is the removal of entrained sand that has reached an abrasive concentration. Many of the sand sections are poorly cemented and are reduced to grain size by the drilling action of the bit. If the mud in use has appreciable gel strength, then the gel strength must be reduced before the fine sand can be settled out. The general practice is to reduce the gel strength with caustic soda and quebracho to a point where the entrained sand content of the mud will remain at 1 per cent or less by volume.

A problem seldom considered is the importance of removing surface pipe cement contamination from the mud as soon as the plug is drilled. From a drilling standpoint there is ordinarily little need for quality mud immediately below the surface pipe. Consequently, it is a general practice to dilute the cement contamination out over a period of several days, resulting in a mud with high filter loss characteristics during the time. It is possible that the high filter loss is responsible for the large diameter holes that develop below the surface pipe and could be eliminated if the cement were treated out to obtain a lower filter loss mud.

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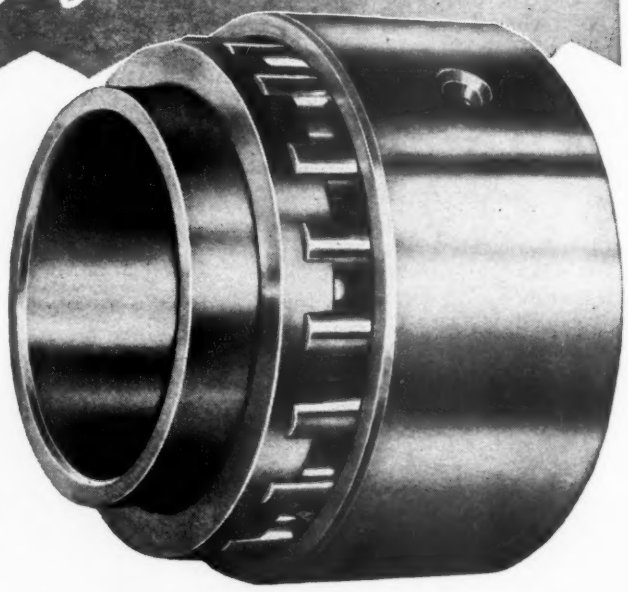

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Engineering characteristics of the Gulf Coast continental shelf*

By M. B. WILLEY, *Chief Engineer*
J. Ray McDermott and Company, Inc.

THE Louisiana "continental shelf is a submarine area which extends seaward for as great a distance as one hundred miles off the present shoreline. The Gulf bottom in this region is characterized by low slopes and its outer margin is outlined by the fifty fathom (300 ft) contour. South of the margin of the shelf the slopes steepen abruptly in the continental slope zone and plunge into the deeps of the Gulf of Mexico."[1]

The engineer who is called upon to design a structure on this shelf is concerned only with the uppermost portion to a depth generally not to exceed 100 to 150 ft. This layer is young in a geological sense, and it has the characteristics usually associated with infancy. A few of these are lack of strength, lack of uniformity, and high water content. It consists of the sedimentary deposits of the various rivers and streams entering the Gulf. These streams are all heavily burdened in quantities sufficient to fill the areas at their mouths, were it not for the fact that continual subsidence, equal or greater in amount and acting directly opposite, prevail over the sedimentary workings of the streams. This subsidence has been estimated by geologists to be at the rate of at least 1 ft per century.

The Mississippi River, which has been the predominant factor in the formation of practically all the Louisiana continental shelf, is one of two rivers flowing into the Gulf that have been able to build protruding deltas. The Mississippi has done so because of its enormous size and load. It deposits sediments in amounts sufficient to replace and actually gain on the amount of subsidence. "The Mississippi at the present time is yearly carrying to the Gulf enough mud and sand to cover an area a mile square to a depth of 268 ft. In the 30,000 years since the glaciers started their slow retreat from the North American Continent, the Mississippi has brought to South Louisiana enough sediment to bury the entire state (48,000 sq mi in area) to a depth of 188 ft. It is obvious to anyone that this sediment has been spread out 'not over the entire state' but over the delta and coastal parishes and over a portion of the shallow water just off shore. Concentrated in this local area, this sediment has caused a corresponding sinking."[2]

These sediments of the Mississippi, augmented to a small extent by the other small rivers and streams, are the materials of the continental shelf along the entire coast of Louisiana. This huge mass of stream deposits is known as the Recent Alluvium and "consists of a sequence of sediments which grades irregularly upward from course, graveliferous sands into progressively finer deposits of sands, silts, and clays."[1] It overlies the Pleistocene (see Fig. I) in depths varying along the coast line from a few feet at the western edge of Louisiana to as much as 350 ft and more in the area south of Houma and New Orleans. The upper or non-graveliferous section of this Recent Alluvium consists of sands, silts, and clays having a maximum known thickness of more than 250 ft near the Gulf shore south of Houma. The outcropping of the Pleistocene can

*Presented before the Fall Meeting of the Petroleum Division, American Institute of Mining and Metallurgical Engineers, Tulsa, Oklahoma, October 8, 9, 10, 1947.

FIG. 1.

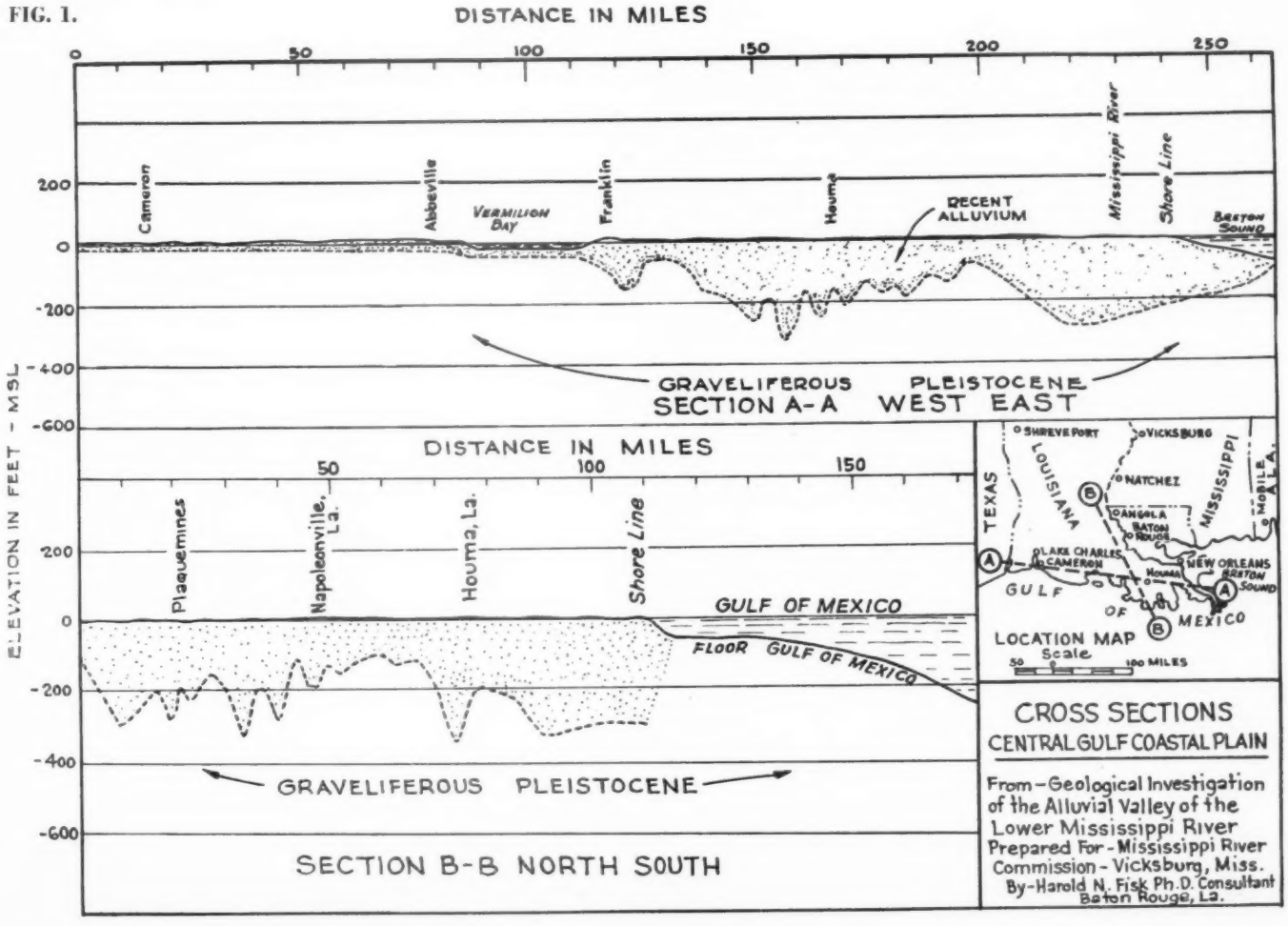


TABLE 1. Borings.
(For location of borings see Fig. 2).

B-1

Water 4 ft deep (MLG)

Elevation MLG, ft	Per cent moisture dry weight	Consistency	Classification
— 5			Gray shells
— 9	60.8	Soft	Gray silty clay
—14	59.7	Medium	Gray silty clay—Tr. humus
—19	43.7	Medium	Gray clay silt
—24	43.7	Medium	Gray clay silt
—29	47.1	Firm	Gray silty clay
—34	67.2	Firm	Gray medium clay

B-2

Water 7 ft deep (MLG)

— 8	400.0	Very soft	Gray clay—40 per cent humus Tr. shells
—12	584.9	Medium	Dark brown humus, clay
—17	363.0	Medium	Dark brown humus—clay
—22	95.3	Soft	Gray med. clay, shells; Tr. humus
—27	46.2	Medium	Gray silty clay
—32	68.4	Medium	Gray medium clay
—37	26.6	Stiff	Gray silty clay
—42	23.2	Very stiff	Brown medium clay (Pleistocene)

B-3

In the drilling of Superior Oil Company's Gulf of Mexico State 1-A (located as T-1, on Fig. 2) only silt and clays of various consistencies were encountered to a depth of more than 1000 ft.

Information—Borings B-1 and B-2: H. A. Huesmann, Chief of Soil Section, U. S. Engineers Office, New Orleans District, New Orleans, Louisiana.

be taken to be at or near the interior edges of the coastal swamps. In western Louisiana the Pleistocene dips south at the rate of about 1 ft per mile and borings of the U. S. Engineers have located it at a depth of about 17 ft beolw Mean Sea Level near Grand Chenier in Cameron Parish, Louisiana. The rate of dip increases gradually as we go eastward until we reach the vicinity of Marsh Island. Here borings have encountered it at a depth of about 40 ft below Mean Sea Level. Continuing eastward this depth increases rapidly due to dipping not only south into the Gulf but also east into the trench of the Mississippi. The area along the remainder of the coast is made up of the numerous deltas of the Mississippi River drainage system, throughout which the Recent Alluvium is extremely thick.

If we glance at the maps of the U. S. Coast and Geodetic Survey covering the continental shelf south of Louisiana we will find that they chart many varied classifications of material as comprising the Gulf floor, including mud, sands, and clays of various consistencies, together with local deposits and reefs of shell. These descriptions apply, of course, only to the surface. Unfortunately, there has been very little data obtained with regard to the nature of the material immediately below the surface. As yet no investigations made preliminary to the installation of offshore structure have included the taking of comprehensive borings; the few wells that have been drilled have not sampled or classified the surface formations and geophysical crews who have bored only to shallow depths have not been interested in the materials encountered.

In this country the standard classification of materials, as found in sedimentary deposits, is that of the Bureau of Soils of the U. S. Department of Agriculture. It is as follows:

Name	Size of particles in Millimeters
Colloids	Less than 0.001
Clay	0.001 to 0.005
Silt	0.005 to 0.05
Very fine sand	0.05 to 0.1
Fine sand	0.1 to 0.25
Medium sand	0.25 to 0.5
Coarse sand	0.5 to 1.0
Fine gravel	1.0 to 2.0

We may rest assured that most structures erected on the continental shelf adjacent to the coast of Louisiana must depend for support on such materials, with an occasional intermingling of a layer or deposit of humus or shell. In general, but not always, they will be more consolidated at the deeper depths and the water content will be lower.

TABLE 2. Pile test T-1.

Company: Superior Oil Company.

Location: See Fig. 2. Water 22 ft deep. Gulf Floor 0.0.

Pile: 7-in. OD steel pipe, 112 ft long, 24 lb per linear ft, T. & C. and welded.

Hammer: No. 1 Vulcan steam. Total weight 21,200 lb. Ram 5000 lb. Stroke 36 in.

Depth of penetration, ft.	Increment, in.	Blows	Penetration per blow, in.	Safe load in tons EN formula
22.0	264	Pile hammer dropped free—15 ft.		
53.0	372	Hammer free on pile		
56.0	36	3	12.0	1.24
58.0	24	5	4.8	3.06
62.0	48	16	3.0	4.84
66.0	48	20	2.4	6.00
68.0	24	13	1.84	7.75
70.0	24	14	1.71	8.30
76.0	72	48	1.5	9.37
78.0	24	15	1.6	8.85
80.0	24	13	1.85	7.71

Contact area of pile: $7/12 \times 3.1416 \times 80 = 147$ sq ft.

Safe load per sq ft contact area:
(EN formula) ..... $15{,}420 \div 147 = 105$ lb.

Pile permitted to set 15 hr before driving resumed.

80.6	7	10	0.70	18.75
81.9	16	20	0.80	16.70
83.6	20	20	1.00	13.63
Total	43	50	0.86	15.65

Contact area of pile: $7/12 \times 3.1416 \times 83.6 = 153$ sq ft.

Safe load per sq ft contact area:
(EN formula) ..... $31{,}300 \div 153 = 204$ lb.

Information by: W. S. Law, Superintendent, Superior Oil Company, Lafayette, Louisiana.

TABLE 3. Pile test T-2

Company: Magnolia Petroleum Company.

Location: See Fig. 2. Water 16 ft deep. Gulf Floor 0.0.

Pile: 15-in. OD steel pipe, 1-in. wall, 120 ft 6 in. long, 149.5 lb per linear ft, welded joints, total weight 18,000 lb.

Hammer: No. 1 Vulcan steam. Total weight 10,200 lb. Ram 5000 lb. Stroke 36 in.

Depth of penetration, ft	Increment, in.	Blows	Penetration per blow, in.	Safe load in tons EN formula*	Safe load in tons Mod. EN formula*
24.0		Weight of pile only.			
60.0		Hammer free on pile			
62.9	34.8	10	3.48	4.2	3.9
65.2	27.6	11	2.51	5.7	5.2
67.0	21.6	13	1.66	8.5	7.4
68.4	16.8	8	2.10	6.8	6.1
70.3	22.8	11	2.07	6.9	6.2
74.7	52.8	32	1.65	8.6	7.5
80.6	70.8	51	1.39	10.1	8.6
85.0	52.8	42	1.26	11.0	9.3
86.7	20.4	21	0.97	14.0	11.3
88.8	25.2	22	1.15	12.0	10.0
90.6	21.6	20	1.08	12.7	10.4
92.3	20.4	20	1.02	13.4	10.9
93.9	19.2	20	0.96	14.1	11.4
95.8	22.8	23	0.99	13.8	11.1
97.0	14.4	20	0.72	18.3	13.9

Contact area of pile: $15/12 \times 3.1416 \times 97.0 = 380$ sq ft.

Safe load per sq ft contact area:
(EN formula)* ..... $36{,}600 \div 380 = 96$ lb.
(Mod. EN formula)* ..... $27{,}800 \div 380 = 73$ lb.

Pile permitted to set 24 hr before driving resumed:

97.08	1.0	9	0.11	71.4	31.9
97.63	6.5	20	0.33	34.9	21.7
98.75	13.5	50	0.27	40.5	23.8
Total	21.0	79	0.266	41.0	24.0

Contact area of pile: $15/12 \times 3.1416 \times 98.75 = 388$ sq. ft.

Safe load per sq ft contact area:
(EN formula)* ..... $82{,}000 \div 388 = 210$ lb.
(Mod. EN formula)* ..... $48{,}000 \div 388 = 124$ lb.

*Mod. EN formula: (Eytelwein) for heavy piles:

*EN formula: $\text{Safe load} = \dfrac{2WH}{S + 0.1}$

$\text{Safe load} = \dfrac{2WH}{S + 0.1\left(\dfrac{\text{Weight of pile}}{\text{Weight of hammer}}\right)}$

Information by: R. G. Watts, assistant chief engineer, Magnolia Petroleum Company, Dallas, Texas.

TABLE 4. Pile test T-3.

Company: Magnolia Petroleum Company.

Location: See Fig. 2. Water 21 ft deep. Gulf Floor 0.0.

Pile: 15-in. OD steel pipe, 1-in. wall, 136 ft long, 149.5 lb per linear ft. Welded joints, total weight 20,332 lb.

Hammer: No. 1 Vulcan steam. Total weight 10,200 lb. Ram 5000 lb. Stroke 36-in.

Depth of penetration, ft	Increment, in.	Blows	Penetration per blow, in.	Safe load in tons EN formula	Safe load in tons Mod. EN formula
17.0		Weight of pile only.			
23.75		Dropped pile 7 ft.			
30.0	75.0	22	3.41	4.3	3.9
35.5		Broke through into mud and dropped.			
42.0	78.0	21	3.71	3.9	3.6
49.0	84.0	20	4.20	3.5	3.2
56.0	84.0	29	2.90	5.0	4.5
59.5	42.0	30	1.40	10.0	8.2
63.5	48.0	30	1.60	8.8	7.4
66.0	30.0	30	1.00	13.6	10.6
69.5	42.0	30	1.40	10.0	8.2
72.0	30.0	30	1.00	13.6	10.6
75.5	42.0	30	1.40	10.0	8.2
77.0	18.0	30	0.60	21.4	14.7
80.0	36.0	51	0.76	17.5	12.7
83.5	42.0	60	0.70	18.8	13.4
86.0	30.0	50	0.60	21.4	14.7
88.5	30.0	50	0.60	21.4	14.7
92.17	44.0	150	0.29	38.5	21.1

Contact area of pile: $15/12 \times 3.1416 \times 92.17 = 362$ sq ft.

Safe load per sq ft contact area:
(EN formula) ..... $77{,}000 \div 362 = 212$ lb.
(Mod. EN formula) ..... $42{,}200 \div 362 = 116$ lb.

Soil classification: 0 to 30 sand and silt (no mud).
30 to 35 soft mud.
35 to 88 blue gumbo (clay) stiffness increasing with depth.
88 to 92.2 very stiff.

Information by: R. G. Watts, assistant chief engineer, Magnolia Petroleum Company, Dallas, Texas.

TABLE 5. Pile test T-4.

Company: Magnolia Petroleum Company.

Location: See Fig. 2. Water 20 ft deep. Gulf Floor 0.0.

Pile: 24-in. OD steel pipe, 160 ft long, 125.5 lb. per linear ft. Welded joints. Total weight 20,080 lb.

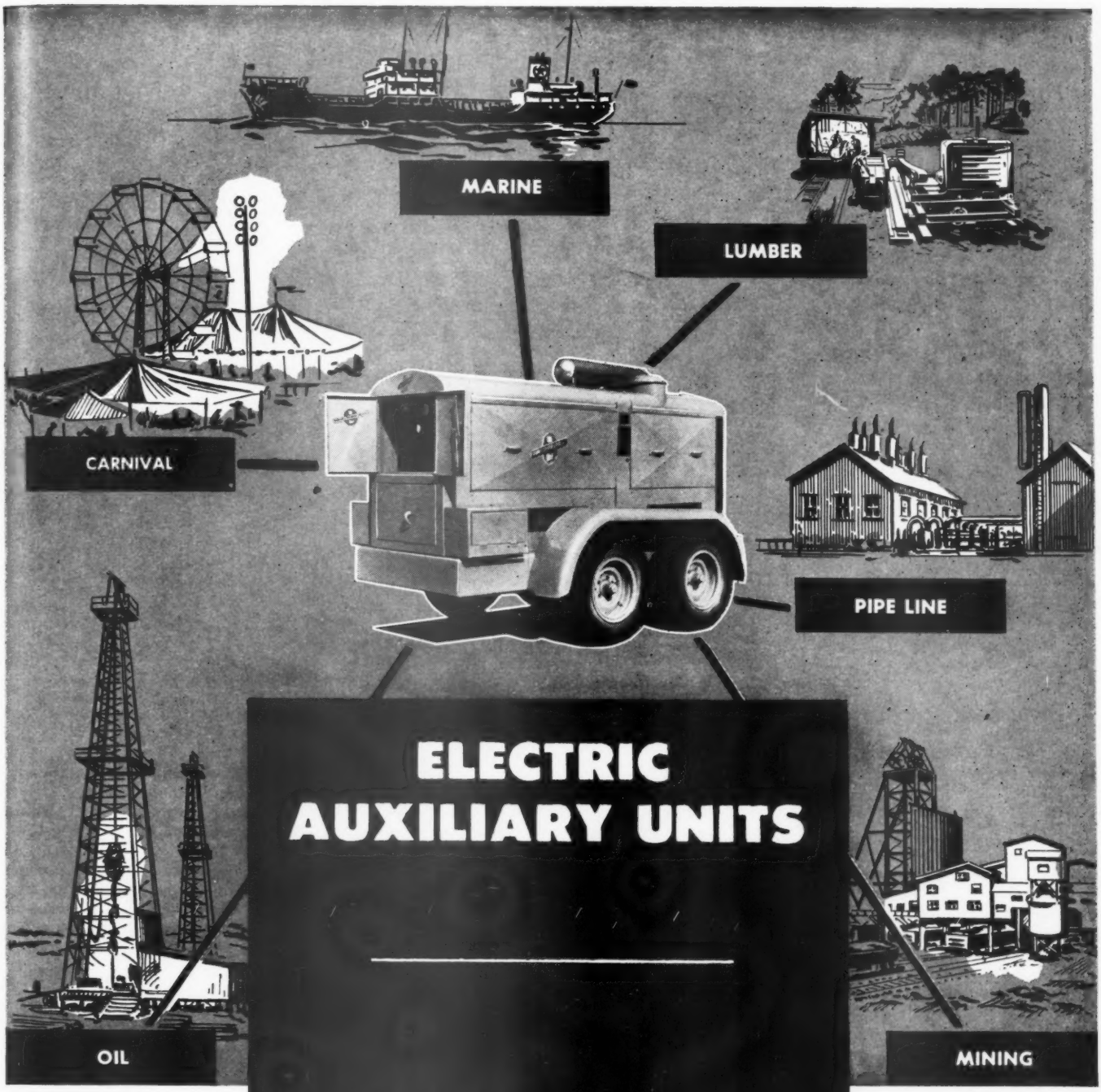
Hammer: No. 0 Warren-Vulcan steam. Total weight 16,250 lb. Ram 7500 lb. Stroke 39-in.

Depth of penetration, ft	Increment, in.	Blows	Penetration per blow, in.	Safe load in tons EN formula	Safe load in tons Mod. EN formula
43.7		Weight of pile only.			
48.7		Hammer free on pile.			
60.7	144	50	2.88	8.2	7.7
63.7	36	25	1.44	15.8	14.2
67.7	48	25	1.92	12.1	11.1
71.7	48	25	1.92	12.1	11.1
74.2	30	25	1.20	18.7	16.5
77.7	42	25	1.68	13.7	12.5
83.2	66	50	1.32	17.2	15.3
85.7	30	25	1.20	18.7	16.5
86.7	12	25	0.48	42.0	32.5
88.2	18	25	0.72	29.7	24.6
88.7	6	25	0.24	71.7	47.8
89.2	6	25	0.24	71.7	47.8
90.2	12	25	0.48	42.0	32.5
90.7	6	25	0.24	71.7	47.8
91.7	12	25	0.48	42.0	32.5
92.2	6	25	0.24	71.7	47.8
92.9	8	25	0.32	58.0	41.2
93.7	7	25	0.28	64.2	44.3
94.2	6	25	0.24	71.7	47.8
94.7	6	25	0.24	71.7	47.8
95.7	12	25	0.48	42.0	32.5
97.2	18	25	0.72	29.7	24.6
98.2	12	25	0.48	42.0	32.5
98.7	6	25	0.24	71.7	47.8
99.7	12	25	0.48	42.0	32.5
100.2	6	25	0.24	71.7	47.8
100.7	6	25	0.24	71.7	47.8

Contact area of pile: $2 \times 3.1416 \times 100.7 = 673$ sq. ft.

Safe load per sq ft contact area:
(EN formula) ..... $143{,}400 \div 632 = 227$ lb.
(Mod. EN formula) ..... $95{,}600 \div 632 = 151$ lb.

Information by: R. G. Watts, assistant chief engineer, Magnolia Petroleum Company, Dallas, Texas.



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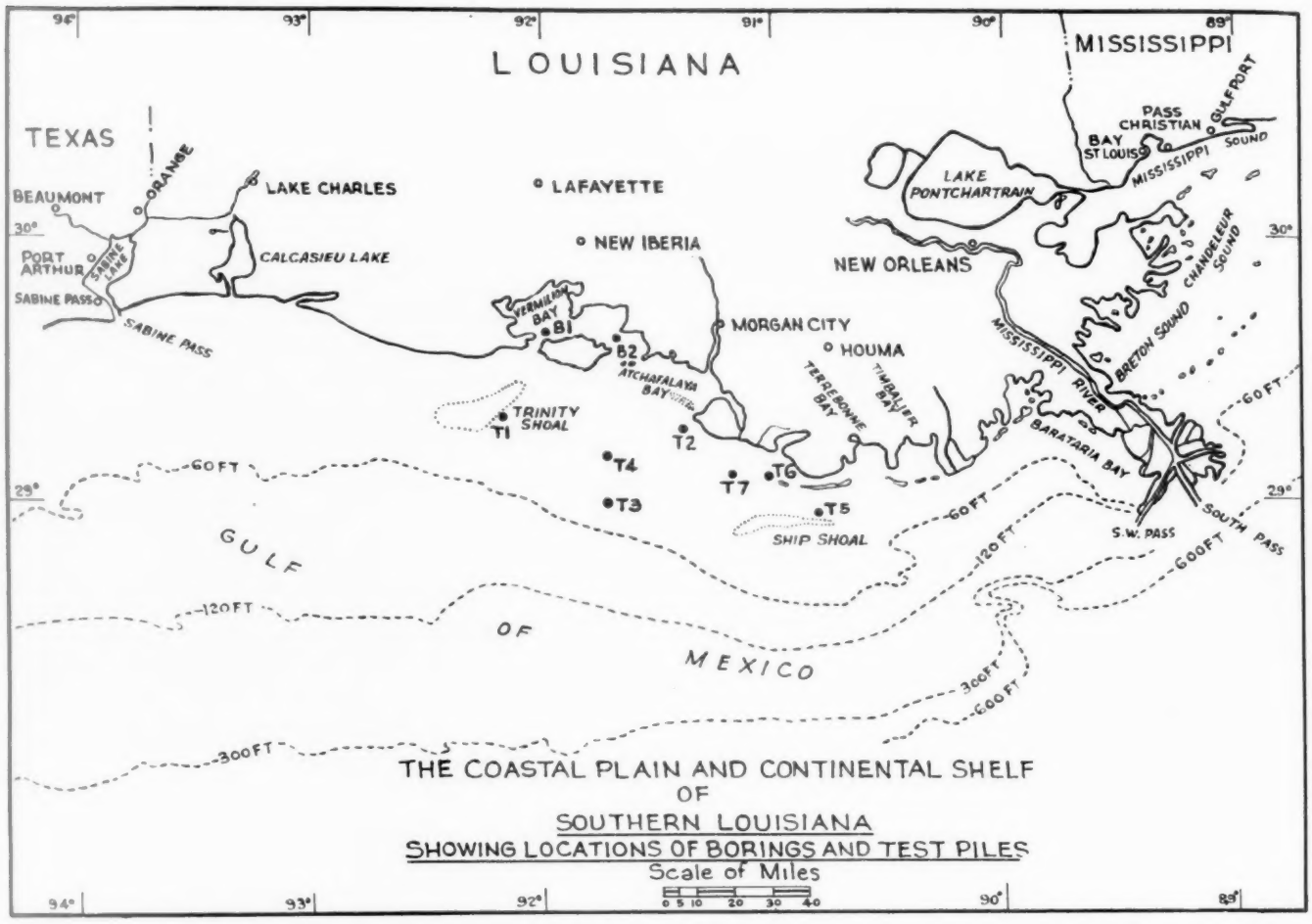

THE COASTAL PLAIN AND CONTINENTAL SHELF
OF
SOUTHERN LOUISIANA
SHOWING LOCATIONS OF BORINGS AND TEST PILES
Scale of Miles

FIG. 2

To the present time the only structures erected offshore in the Gulf of Mexico have been those required for the drilling of exploratory oil wells and in all cases these have used piles to support the elevated platforms. As would be expected, the results of the driving of test piling in these various locations show considerable variation. (See Fig. 2 and Tables 2 to 9, inclusive.) All are in the area in which the Recent Alluvium is thick and it is certain that in none of them has piling reached the Pleistocene. The resistance supporting these piles is due to the friction of the earth against the side of pile, with little or no assistance from actual bearing at the point. Fortunately, the silts, clays, and sands of these sedimentary deposits have a fairly high shearing value and, what is even more fortunate, they possess the ability to set or freeze around the pile after it has remained in place for a period of time.

In Table 9 the results of the driving of seven test piling in the area presently active off the Louisiana Coast have been summarized. These tests included one creosoted fir and six steel piling of various diameters. By converting to a unit of safe load per sq ft of contact area a fair basis for comparing these results is obtained. Only three of the tests included the redriving of the piles after a period of rest. Although these rest periods were comparatively short, varying from 15 to 24 hr, the safe load in each case practically doubled. One pile, on which a load test was carried out after 12-hr rest, increased approximately 75 per cent. It is my opinion that 24-hr rest is insufficient to attain the maximum amount of freeze, but what time interval is actually required can only be determined by further and more extended tests.

Terzaghi states that this freezing action "is thought to be caused by the squeezing of a certain quantity of water out of the soil beneath the point of the pile in driving. The water escapes toward the surface through the space between the pile and the ground and forms a film acting as a lubricant against the side of the pile. During a period of rest the film of water is gradually absorbed by the soil and the full static pile friction develops." [3] It is possible that this action is aided by the settling of the coarser non-cohesive sands and gravels against the side of the pile during the driving period while the surrounding earth is being agitated. Upon stabilizing these materials produce an increase in the coefficient of friction of the surface in contact with the pile. This property of sands to rise to, and tighten at, the surface when agitated is well known.

Regardless of the cause of this setting its actual occurrence is undeniable. If structures are built on piles driven into saturated silts, clays, and fine sands, on the basis of driving tests that do not take into consideration this set the provider of funds for them need have no worry concerning their possible failure, but he should (especially with piling costs as at present) examine his bank balance very carefully.

Until further and more comprehensive tests are made that will provide definite knowledge of the total increase in bearing capacity due to this freezing action and the extent of time required to reach this maximum, designs will have

TABLE 6. Pile test T-5.

Company: Magnolia Petroleum Company.
Location: See Fig. 2. Water 26 ft deep. Gulf Floor 0.0.
Pile: 8⅛-in. OD steel pipe, 132 ft long, 38.42 lb per linear ft.
Hammer: No. 0 Warren-Vulcan steam. Total weight 16,250 lb. Ram 7500 lb. Stroke 39 in.

Depth of penetration, ft	Increment, in.	Blows	Penetration per blow, in.	Safe load in tons EN formula
0.5		Weight of pile.		
3.75		Hammer free on pile.		
10.0	75	25	3.0	7.9
11.5	18	25	0.72	29.8
13.75	27	50	0.54	38.1
17.0	39	25	1.56	14.7
22.0	60	25	2.4	9.8
29.5	90	25	3.6	6.6
37.5	96	25	3.84	6.2
44.5	84	25	3.36	7.0
49.5	60	25	2.4	9.8
57.5	96	25	3.84	6.2
63.5	72	25	2.88	8.2
83.5	240	100	2.4	9.8
88.0	54	25	2.16	10.8
91.5	42	25	1.68	13.7
94.0	30	25	1.20	18.8

Contact area of pile: $\frac{8.125}{12} \times 3.1416 \times 94 = 200$ sq ft.

Safe load per sq ft contact area:
(EN formula).....37,600÷200=188 lb.

Soil classification: Very stiff clay from depth of 4 to 10 ft.
Very soft layer 14 to 38 ft.
Stiffening continuously below.

Information by: R. G. Watts, assistant chief engineer, Magnolia Petroleum Company, Dallas, Texas.

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TABLE 7. Pile test T-6.

Company: Stanolind Oil & Gas Company.

Location: See Fig. 2. Water 9 ft deep. Gulf Floor 0.0.

Pile: 100 ft creosoted fir, diameter 10 ft intervals from tip: 0 ft (tip) 6.84 in; 10 ft 8.91 in.; 20 ft 10.66 in; 30 ft 12.18 in.; 40 ft 12.97 in.; 50 ft 14.00 in; 60 ft 14.56 in.; 70 ft 14.88 in.; 80 ft 15.12 in.; 90 ft 15.75 in.; 100 ft (butt) 16.63 in. Computed weight of piling, 3200 lb (approx.).

Hammer: 50C Super Vulcan. Total weight 11,845 lb. Ram 5000 lb. Normal stroke 15½ in., equivalent stroke 3 ft.

Load test: Made with Tinus Olson 100 ton hydraulic compression machine between pile and build-up girder, framed between four hold-down piles.

Depth of penetration, ft	Increment, in.	Blows	Penetration per blow, in.	Safe load in tons EN formula
20.8		Weight of pile.		
52.0		Hammer free on pile.		
55.0	36.0	10	3.6	4.1
58.5	42.0	10	4.2	3.5
62.0	42.0	10	4.2	3.5
64.5	30.0	10	3.0	4.8
67.1	31.2	10	3.12	4.7
68.8	20.4	10	2.04	7.0
70.9	25.2	10	2.52	5.7
72.5	19.2	10	1.92	7.4
73.8	15.6	10	1.56	9.0
75.3	18.0	11	1.64	8.6
76.8	18.0	10	1.80	7.9
78.0	14.4	10	1.44	9.7
79.3	15.6	11	1.42	9.9
80.8	18.0	10	1.80	7.9
81.9	13.2	11	1.20	11.5
82.9	12.0	10	1.20	11.5
83.8	10.8	10	1.08	12.7
84.8	12.0	10	1.20	11.5
85.6	9.6	10	0.96	14.1
86.6	12.0	10	1.20	11.5

Approximate contact area of pile, 280 sq ft.

Safe load per sq ft contact area:
(EN formula).....23,000÷280=82 lb.

Load test applied after pile set 24 hr:

Load	Applied, hr	Settlement	Cumulative settlement
10 tons	36	0	
20 tons	6	1/16 in.	
30 tons	6	0	1/16 in.
40 tons	1/12	3/16 in.	5/16 in.
41 tons	1/12	1/4 in.	7/16 in.
41–50 tons		Movement continuous.	

By load settlement graph—indicated safe working load—40,000 lb.

Safe load per sq ft contact area: (Load test) 40,000÷280=143 lb.

Information by John Evans, Stanolind Oil and Gas Company, Tulsa, Oklahoma.

*Apparent settlement attributed to compression in top fibers of unevenly sawed pipe.

TABLE 8. Pile test T-7.

Company: Kerr-McGee Oil Industries, Inc., Oklahoma City, Oklahoma.

Location: See Fig. 2. Water 18 ft deep. Gulf Floor 0.0.

Pile: 10-in. OD steel pipe, 120 ft long.

Hammer: No. 1 Vulcan steam. Total weight 10,200 lb. Ram 5000 lb. Stroke 36 in.

Depth of penetration, ft	Increment, in.	Blows	Penetration per blow, in.	Safe load in tons EN formula
33.5		Weight of pile.		
38.5		Pulled with pile line		
39.1		Weight pile with hammer.		
42.0	35	11	3.2	4.6
69.3	328	10	32.8	0.5
72.6	39	10	3.9	3.8
75.5	35	10	3.5	4.2
78.8	39	10	3.9	3.8
80.7	23	10	2.3	6.2
82.8	25	10	2.5	5.7
84.6	22	10	2.2	6.5
86.7	25	10	2.5	5.7
88.5	22	10	2.2	6.5
90.2	20	10	2.0	7.2
92.0	20	10	2.0	7.2

Contact area of pile: 10/12×3.1416×92=241 sq ft.

Safe load per sq ft contact area:
(EN formula).....14,400÷241=60 lb.

Pile permitted to set 23 hr before driving resumed.

92.5	6	10	0.6	21.4
93.0	6	9	0.67	19.5
93.5	6	8	0.75	17.6
94.0	6	9	0.67	19.5
94.5	6	9	0.67	19.5
95.0	6	8	0.75	17.6
95.5	6	8	0.75	17.6
96.0	6	8	0.75	17.6

Contact area of pile: 10/12×3.1416×96=252 sq. ft.

Safe load per sq ft contact area:
(EN formula).....35,200÷252=140 lb.

Information by: Tom Seale, chief engineer, Kerr-McGee Oil Industries, Oklahoma City, Oklahoma.

to be based on known safe loading capacities that are probably very conservative. Magnolia, on its first location, used a loading of 50,000 lb per 15-in OD steel pipe piles with a penetration of about 98 ft. This is a unit load of 130 lb per sq ft of contact surface. Table 3 shows the test on one pile of a group of three driven at this location in the preliminary investigation. It is probable that a load of 50,000 lb per pile was reached if not exceeded during drilling operations. About one year after the installation of this foundation the piling were pulled. A pull of more than 200,000 lb could not loosen the piling, even in conjunction with a jet extending down approximately one-half of the pile penetration. Only by lowering the jet to within about 25 ft of the pile tip could it be removed.

It can safely be assumed that the force required to extract the pile, less its actual weight, is a close approximation of the static friction that can be used as a maximum value in design. Completely discounting the area of contact surface eliminated by the jetting action, the unit force required to pull the pile amounted to at least 500 lb per sq ft. It is probable, considering the surface area on which friction was partially or totally destroyed by the jet, that the static friction amounted to 750 lb or more per sq ft. If such is the case, after maximum set is obtained then design loading can be considerably increased, say to 250 lb per sq ft of contact surface, and still retain a safety factor of 3 to 1. This would bring about large savings in material and erection costs.

To obtain a working knowledge of this probable increased hearing capacity after maximum freeze an actual static load test would be required. A suggested load test is to drive four piling in the form of a square, install a deck and erect a 2000-bbl tank thereon. After driving the piling should be permitted to set for at least two weeks before the test is begun. By alternately jumping in and withdrawing water, allowing the structure to remain in both loaded and unloaded state for several hours, increasing the amount of water each time the tank is reloaded, a close approach to actual working conditions will be obtained. When full of sea water the tank and superstructure will impose a load of more than 180,000 lb per pile, which (unless pile diameter and length is excessive) should produce some settlement, and possibly a failure. The results thus obtained, correlated with the analysis of a soil technician, will provide a true basis for design.

There has been little, if any, use of soil mechanics in the design of offshore structures up to the present time. This science, which in recent years has attained full recognition as an important branch of engineering, can be profitably employed in preliminary investigations of structures to be built on the continental shelf. An examination of the materials encountered to determine water content, clay content, water plasticity ratio of clays, cohesion in silts and clays, and other tests made by qualified soil technicians can provide a close check of the results of driving and load tests, and discover unconformities in the various layers that would lead to a correct determination of piling lengths and give other assistance to the proper solution of the problem. After the erection and use of the first structure in any given area additional installations can no doubt be safely designed by the correlation of test borings in conjunction with the driving of a single test pile.

The foregoing has dealt with piling type foundations only. On the Louisiana continental shelf it is probable that no other types are applicable, with the possible exception of a small area close to shore where the water is shallow and wave action is minimized by protecting reefs. Drilling barges have been used successfully where the depth of water is commensurate with their draft, by first placing a compacted shell mat over the area on which the barge is placed. Trouble has been experienced with tilting of drilling barges used on the natural Gulf floor without providing a mattress. It is probable that if the wave action was considerable in amount and directed continuously against one side of the barge for an extended period, sufficient undercutting would result to endanger the operation, even with the use of a mat.

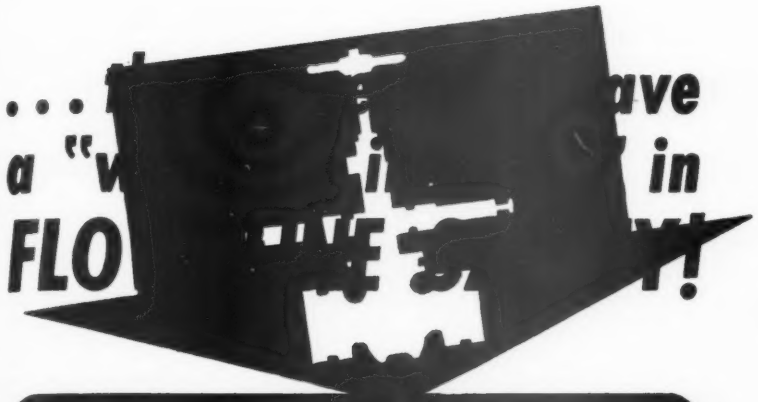
In the case of a drilling barge considerable amount of the total load is supported by the buoyancy of the partially submerged pontoons and only a small portion is carried by the earth below. If an attempt was made to use a nonbuoyant mat, the entire load would be imposed upon the soil directly below it. The area of the mat should be sufficient to stay within the safe bearing capacity of the Gulf floor. Unquestionably this bearing capacity is, with a few exceptions, quite low. Furthermore, with

TABLE 9. Summary. Test pile data.

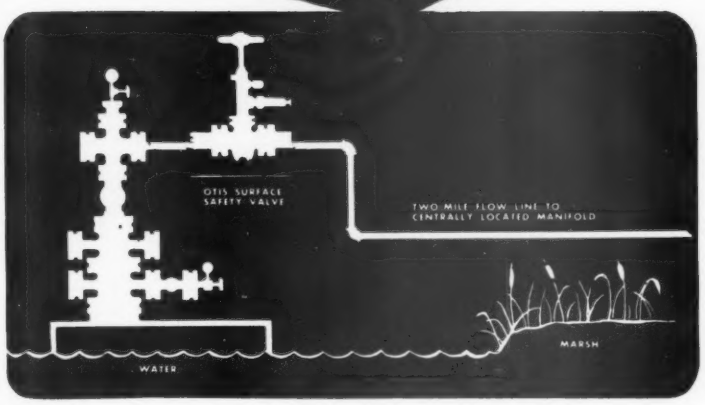
Test no.	Pile			Total penetration before rest, ft	Safe load	Safe load, lb per sq ft contact surface	Rest period, hr	Total penetration after redriving, ft	Safe load	Safe load, lb per sq ft contact area
	Material	Size	Length							
T-1	Steel pipe	7 in. OD	112 ft	80.0	*7.71	105	15	83.6	*15.65	204
T-2	Steel pipe	15 in. OD	120 ft 6 in.	97.0	†13.9	73	24	98.75	†24.0	124
T-3	Steel pipe	15 in. OD	135 ft	92.17	†21.1	116		Not included		
T-4	Steel pipe	24 in. OD	160 ft	100.7	†47.8	151		Not included		
T-5	Steel pipe	8⅛ in. OD	132 ft	94.0	*18.8	188		Not included		
T-6	Creo. fir	7 in tip 16 in. butt	100 ft	86.6	*11.5	82	24	Load test		143
T-7	Steel pipe	10 in. OD	120 ft	92.0	* 7.2	60	23	96.0	*17.6	140

*Engineering News Formula (weight of pile less than weight of ram).

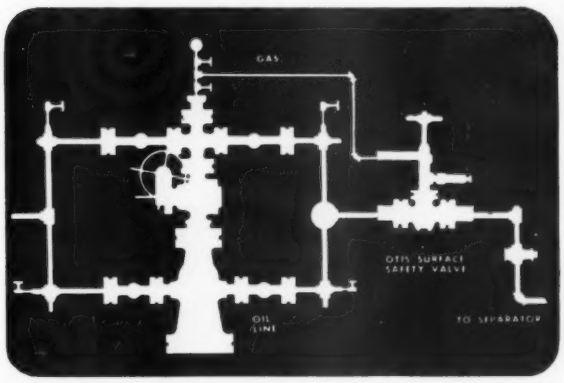
†Mod. Engineering News Formula (heavy piles).



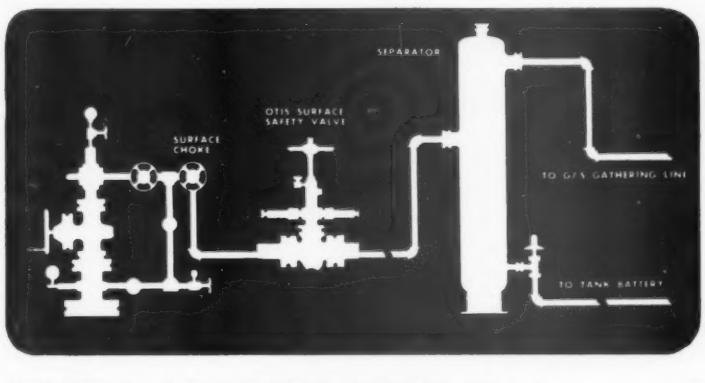
OTIS SURFACE SAFETY VALVE



TYPE WELL: Gas-distillate (highly-corrosive). **FLOWING PRESSURE:** 3700 p.s.i. **OPERATING CONDITIONS:** Well is located in a canal and is accessible only by boat. Flow line runs through marshy terrain to a centrally-located manifold approximately two miles away. Entire area is subject to seasonal storms and high water, while the canal carries heavy barge and boat traffic. If a line break should occur considerable time would be lost before the well could be reached and shut in. Furthermore, operating personnel would be in extreme danger if the break is located near the Xmas tree. **APPLICATION OF OTIS SURFACE SAFETY VALVE:** A Type XAB Otis Surface Safety Valve (a full-opening pressure-operated gate valve equipped with a low-pressure pilot) has been installed in the flow wing and is operated by pressure furnished from within the line. In case a line breaks and pressure drops below 3150 p.s.i. (that for which the Valve is set to close) the low-pressure pilot is actuated and causes the gate to automatically snap shut and remain closed until manually opened.



TYPE WELL: Dual-completion (gas and oil). **OPERATING CONDITIONS:** This well has been completed in a lower gas sand and an upper oil pay. Shut-in pressure of the gas formation is considerably higher than flowing pressure of the oil sand. The gas flow line is subject to freezing and the resulting high pressures build up beneath and threaten to unseat the packer, separating the two zones, if the oil zone which flows through the casing annulus is not immediately closed in. **APPLICATION OF OTIS SURFACE SAFETY VALVE:** A Type ZAD Otis Surface Safety Valve (equipped with a high-pressure pilot) is installed in the oil flow line, but is operated by pressure from the gas line. The pilot is set to close in the oil line when pressure on the gas line reaches 2150 p.s.i. This action allows sufficient pressure to build up above the packer and hold it in place against increased pressure of the lower gas zone.



TYPE WELL: Gas-distillate. **FLOWING PRESSURE:** 725 p.s.i. **OPERATING CONDITIONS:** This well is flowing into a separator, from which point gas is delivered to a gas gathering line which normally carries 600 p.s.i. The safety head in the separator ruptures at 765 p.s.i. During winter months freeze-ups in the gathering line cause pressure to increase to approximately 750-800 p.s.i. at the well head and separator. **APPLICATION OF OTIS SURFACE SAFETY VALVE:** A Type XBD Otis Surface Safety Valve (equipped with both a high-pressure and low-pressure pilot) has been installed in the flow line immediately downstream from the surface choke. The high-pressure pilot is set at 740 p.s.i. and will cause the Valve to automatically shut in the well when line pressure increases to that point, thus preventing dangerous high pressures from being placed on the separator. The low-pressure pilot is set at 450 p.s.i. and will also close the well in if a break or dangerous leak occurs in the flow line, or if the separator safety head ruptures.

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mats heavily loaded and large in area pressures are carried down to a considerable depth and, as evidenced by some of the pile tests given in the tables, could easily reach into an underlying soft compressible stratum. The result would be considerable settlement, which, if unequal, would endanger the structure.

The above remarks have applied specifically to the Louisiana continental shelf inasmuch as all offshore exploratory drilling has, so far, been concentrated in this area. Until these operations are extended into other sections, preliminary investigations made, and structures actually installed, only general inferences concerning them can be made. Apparently, conditions similar to those encountered adjacent to Louisiana will apply along the coasts of Mississippi and Alabama. However, as we continue into the extensive shelf off Florida we enter an area very different. Here the surface is largely sand, shell, and coral and the bearing capacities will be much greater. If coral is encountered, as in one location made offshore of the Florida Keys, the full strength of the pile acting as a column will be developed.

The remaining portion of the Gulf Coast continental shelf—that part bordering the State of Texas—varies considerably from the others, at least insofar as surface conditions are concerned. At the southern extremity the continental shelf is much narrower and steeper, in fact along practically the entire Texas coast the slope of the shelf from the shore to the 30-ft depth contour is much sharper than is general elsewhere. The upper layer of the Pleistocene in this area consists of clay and marl, interbeded with lentils of clay. Along the coast it is reached at comparatively shallow depths, usually about 6 to 10 ft. The overburden consists largely of windblown sands and silts. The rivers of Texas are not heavily loaded with sediment, except during flood stages, and for this reason it can be assumed that the alluvial deposits found on the shelf will not be of great thickness. If the upper layer of the Pleistocene can be reached by piling, comparatively good bearing values should be obtained; however, preliminary investigations prior to the design and construction of the first installations in this area should be very thorough as there is great danger of encountering a layer of loose unconsolidated sands, which would prove a possible cause of failure unless proper provisions are made. Detailed knowledge of the characteristics of the continental shelf in this region must await actual subsurface investigations.

Although the available data are limited, such information as we have points definitely to the imperative need for complete knowledge concerning the conditions at the site of each job. The mere driving of test piling is not enough. Load tests of piling groups should be carried out and the knowledge thus obtained, in conjunction with soil analyses from actual borings, should be used as the basic design. Such procedure is warranted by the financial outlay required to construct even the simplest structure in relatively deep water at considerable distances off-shore and the tremendous loss that would be experienced if a failure occurred. The large sums that are often expended without acquiring such knowledge is a source of amazement. Actually, money spent for thorough preliminary research will generally prove to be far from wasted as it will usually lead to improvements in design, which will decrease the cost of material and construction in an amount far in excess of the expense of the investigation.

● **Acknowledgments.** Wherever possible suitable references as to the source of information have been given. Particular thanks is due H. A. Huesmann, chief of the Soil Section, U. S. Engineers, New Orleans District, New Orleans, Louisiana, for information and suggestions he has given. Denery Picard, W. P. Cullen, and Mrs. C. M. Thibodeaux, of the staff of J. Ray McDermott and Company, Inc., were of great assistance checking and correcting the manuscript and preparing it for printing.

● **References:**

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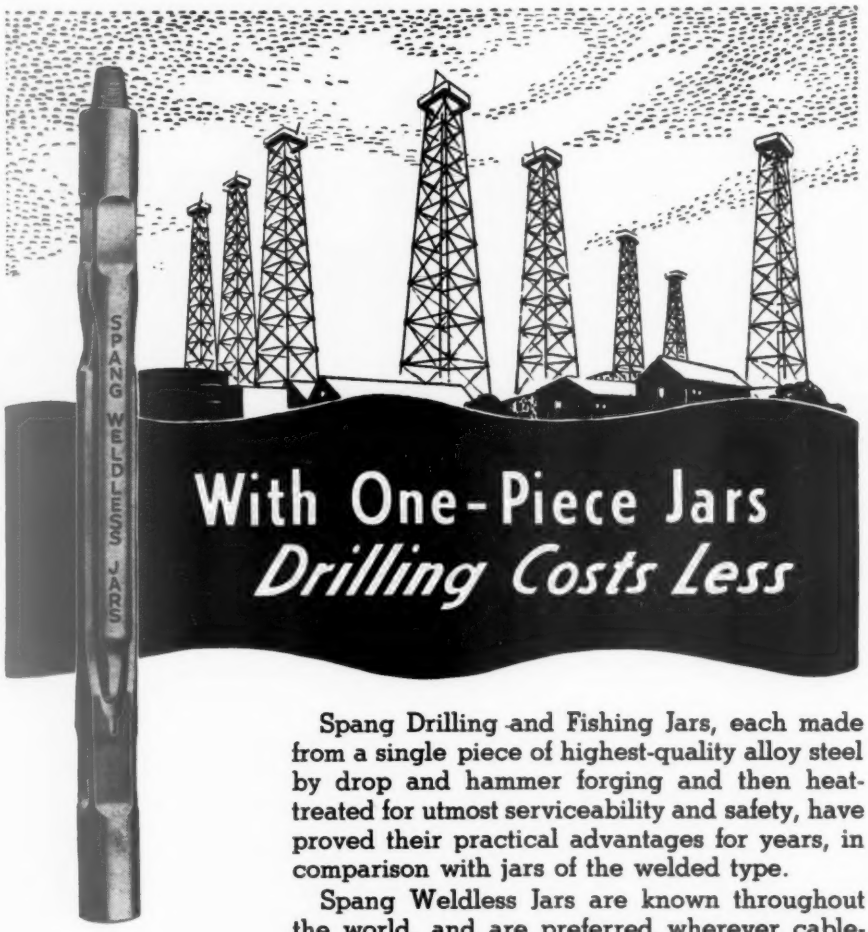

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Field results of jet perforator charges*

By ROBERT HARCUS, Byron Jackson Company

● **Abstract.** A review is made of the various applications of the Jet Process of well servicing. The benefits that may accrue to the oil industry are indicated and the progress of development is outlined. Results of experiments on a field scale in casing severing and perforating in open-hole are described. Casing perforating operations on a commercial basis from the end of September, 1947, to the beginning of March, 1948, are analyzed and a comparison made with bullet perforating. The effect of the jet on a producing sand is discussed on the basis of evidence presented by microphotographs.

● **Introduction.** The results obtained with lined shaped charges in penetrating steel, concrete, natural rock formations, and the like, have placed a new tool at the disposal of the petroleum industry — a tool capable of overcoming many heretofore insurmountable obstacles.

It is generally recognized that the production of petroleum in this country lags behind current requirements, hence the development of reserves for future production is cause for serious concern. Any new development that can reasonably be expected to augment the present oil supply, and the proven reserves, is therefore of vital interest to petroleum engineers, and important from the standpoint of national welfare and security.

● **Anticipated benefits of jet process.** The benefits of the Jet Process, as presently visualized, that may be expected to accrue to the oil industry, and hence to the nation, are as follows:

Increased production: (1) Obtaining oil from previously non-productive reservoirs; (2) overcoming natural or man-made barriers blocking production; (3) increasing the productivity of producing reservoirs as result of deeper penetration; (4) increasing the effects of acidizing; and, (5) improving the effectiveness of secondary recovery methods.

Increased drilling rates in excessively hard formation.

Recovery of well pipe, thereby alleviating the steel shortage, and making maximum economic use of existing casing.

● **Increased production.** Reservoir engineers have long recognized that a vast amount of oil exists in reservoirs that may have been tapped by wells, but is locked in either by natural or man-made barriers that prevent its recovery. The most common natural barrier is hard, tight formation in which oil is stored, the permeability of which is of such a low order that the oil cannot flow through the interstices and drain into the well, even though the formation pressure may be high. It is considered that such formations can be made to produce by deep penetration through flow channels formed directly by the jets from lined shaped charges, also by the formation of cracks or fissures radiating from the jet holes. The present practice of setting off heavy charges of nitroglycerin in the well has undoubtedly aided production from tight formations, but by reason of the dispersed effect of the explosion its effectiveness is limited in comparison to the concentrated and selective action obtainable with lined shaped charges. Of equal, if not greater, import than the removal of natural barriers is the penetration of man-made barriers. The problem of obtaining greater penetration than is possible with existing methods continues to demand the attention of petroleum engineers as more and more becomes known concerning the deleterious effects of drilling fluids on oil-bearing formations. From a drilling standpoint one of the main functions of mud-laden fluid is to build up an impermeable sheath on the walls of the hole. Water or other filtrate from the drilling fluid also permeates the surrounding formation for a distance of from several inches to a foot or more, depending on the permeability of the formation, the characteristics of the filter cake, and the formation pressure. The problem of the production engineer is to devise ways and means of overcoming this water-wet zone surrounding the well bore that frequently acts as a barrier and prevents the flow of oil from the formation into the well, and in such cases the barrier must be perforated in order to obtain production.

It is generally recognized that the bullet method of casing perforating, which has been standard practice prior to the advent of the Jet Process, has not been effective in a large number of cases in penetrating the formation beyond the water barrier, for after penetrating even a single string of casing the bullets have had insufficient momentum left to penetrate a material distance into the formation.

Multiple strings of casing constitute another man-made barrier to production, which in many cases cannot be perforated by the bullet type of perforator, but which can be perforated by lined shaped charges. Three concentric strings of casing, the cement annulus between strings, and several inches of cement outside the outer string, have consistently been perforated with lined shaped charges.

A large proportion of the oil produced in this country comes from limestone formations. It is common practice to treat such formation with acid to enlarge the interstices, and thus facilitate the flow of oil into the wells. The effectiveness of the acidizing operation should be greatly enhanced by firing a series of lined shaped charges prior to acidizing. The holes formed by the jets as well as the cracks that developed radially from the hole must expose a greater area to

*Presented before the Spring Meeting of the Pacific Coast District, Division of Production, American Petroleum Institute, Los Angeles, California, May 6-7, 1948.

APPENDIX I

Summary of Perfo-Jet operations from October 1947 to February 1948.

Ref. no.	Date	Carriers			Charges		Shooting depth, ft		Fluid in hole	Temperature	Remarks
		OD, in.	Shots/ ft	Runs	Type	Total	From	To			
	(1947)										
1	9/20	5	2	7	A	80	4905	4945	Water	Fairly high	See also Ref. Nos. 6, 11, 14, 18, 19, 23, 77.
2	9/24	3⅜	4	2	Local & trial	48	8168	8175	Mud	210 F.	Three misfires. Carrier left in hole on second run. Bullet gun had stuck previously.
3	9/30	5	2	10	A	36	1552	1570	Mud	Low	—
4	10/9	5	2	14	A	168	5843	5930	Oil	Hot	12 misfires due to locating collars on first run in high temperature well.
5	10/16	5	4	4	A	96	2845	2860	Mud		—
6	10/23	5	2-6	16	A	192	4500	4600	Mud		—
7	10/27	5	2	17	A	204	3818	3920	Oil		—
8	10/28	5	2 & 4	8	A	108	5600	5650	Oil	Hot	—
9	10/29	5	2	7	A	84	4370	4400	Oil	Hot	—
10	10/31	5	8	4	A	84	2228	2239	Oil		—
11	10/31	5	2	29	A	348	4200	4400	Water	Hot	—
12	11/3	5	4	8	A	192	6612	6660	Oil	185 F.	—
13	11/3	5	2	51	A	636	6600	7600	Oil	165 F.	14 misfires.
14	11/13	5	12	6	A	72	3707	3842	Water		—
15	11/14	5	4	48	A	1112	2842	3126	Water		—
16	11/15	5	6	1	A	24	3269	3273	Water	118 F.	See also Ref. No. 44.
17	11/15	5	2	2	A	24	2335	2353	Water		See Ref. No. 58 for completion of job.
18	11/17	5	2	7	A	74	3645	3475	Water		—
19	11/19	5	2	13	A	156	3482	3560	Water		—
20	11/19	5	6	2	A	30	2705	2710	Water	121 F.	—
21	11/21	5	4	6	A	140	3160	3195	Oil	125 F.	—
22	11/22	5	2	4	A	48	3505	3592	Water		See also Ref. No. 25.

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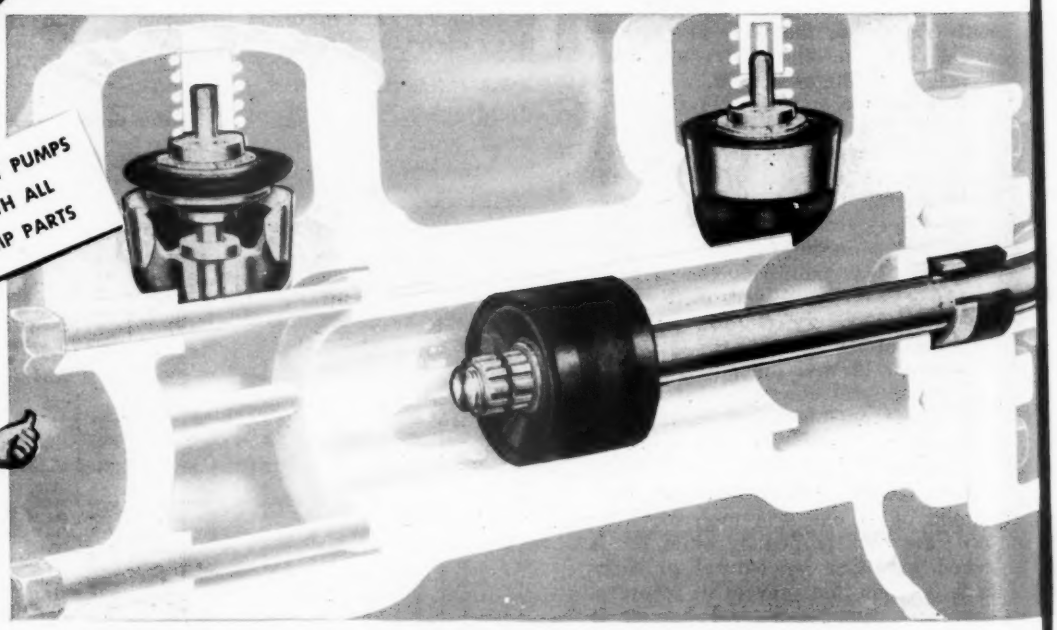

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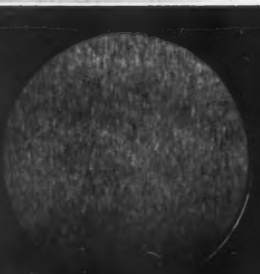
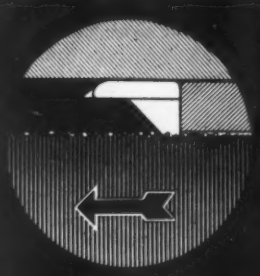
This enlarged photo of the finely ground surface of a Mission "File Hard" Rod shows the microscopic grooves that wear the packing and carry fine sand into the packing where it sticks and cuts the rod.

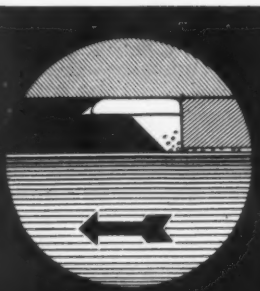


This enlarged photo shows the "Satin Finish" surface now supplied on Mission "File Hard" Rods. Notice the absence of sharp irregularities to wear the packing and catch sand.

This schematic drawing shows how sand is pulled into the packing by the ridged surface of a ground rod. These sand particles become imbedded in the packing and cut the rod.



Since the smooth surface of the Mission Satin Finish Rod does not carry sand into the packing, the rod wear from sand imbedded in the packing is considerably reduced.



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the action of the acid than would otherwise be the case.

Many wells into which the oil will not drain naturally are produced by secondary recovery methods, such as water flooding and gas injection. The injection of the driving medium should be facilitated by firing lined shaped charges in the input well to penetrate or break down any natural or man-made barrier that may impede the flow of the driving medium into the formation.

● **Increased drilling rates.** Another potentially valuable and important application of lined shaped charges may prove to be their use in penetrating the extremely hard formations encountered in certain areas during drilling operations. The penetration of such formations by a conventional drilling bit is often measured in inches whereas it should be possible to penetrate 1, 2, or 3 ft with a single lined shaped charge. The cost of operating a heavy duty rig is considerable and the saving in time alone by the use of lined shaped charges may prove to be a very material factor.

● **Recovery of well pipe.** Development of a special lined shaped charge for severing casing bids fair to be an especially beneficial aspect of the Jet Process. The recovery of casing from wells scheduled for abandonment, also recovery of upper portions of multiple strings in active wells, may become a major project because of the serious shortage of new casing. The use of lined shaped charges for this purpose offers an unusually rapid and effective means of severing casing at any desired point in the well. A comparable use of lined shaped charges of the casing-severing type is the cutting of drill pipe that has become stuck during drilling operations. The conventional method often requires several days to complete a single cutting operation, whereas the time required to complete a severing operation, using a lined shaped charge, can be measured in minutes.

● **Progress of development.** The following applications have been investigated at Byron Jackson Company's experimental station at Long Beach and at duPont's Laboratory in New Jersey:

(1). Explosive charges suitable for perforation of oil well casings.

(2). Design of expendable and non-expendable carriers for jet perforator charges.

(3). Explosives and detonators for high temperature and high pressure conditions in deep wells.

(4). Explosive charges for open-hole shooting.

(5). Charges for internal and external cutting of casing, drill pipe, and tubing.

(6). Bottom-hole and directional charges.

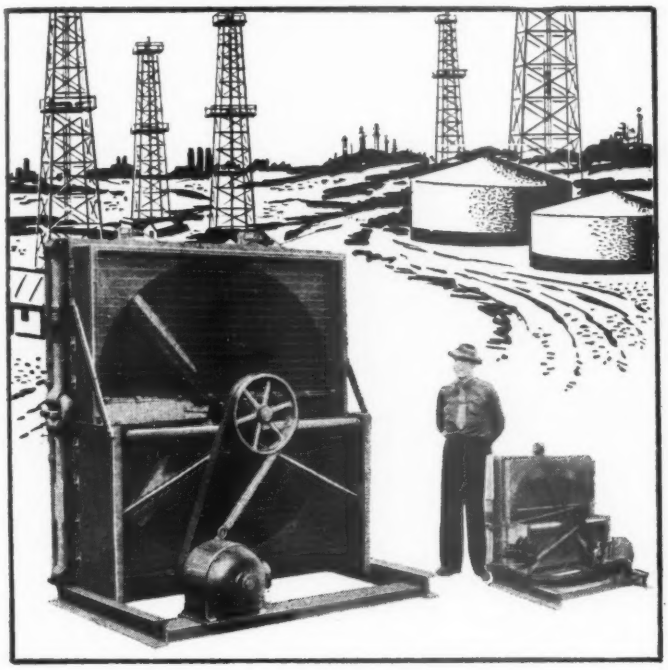
The development of suitable explosives, focusing of the explosive jet, design and fabrication of explosive charges and the manufacture of carriers for these charges has engaged the undivided attention of those responsible for pioneering the Jet Process.

APPENDIX I (continued)

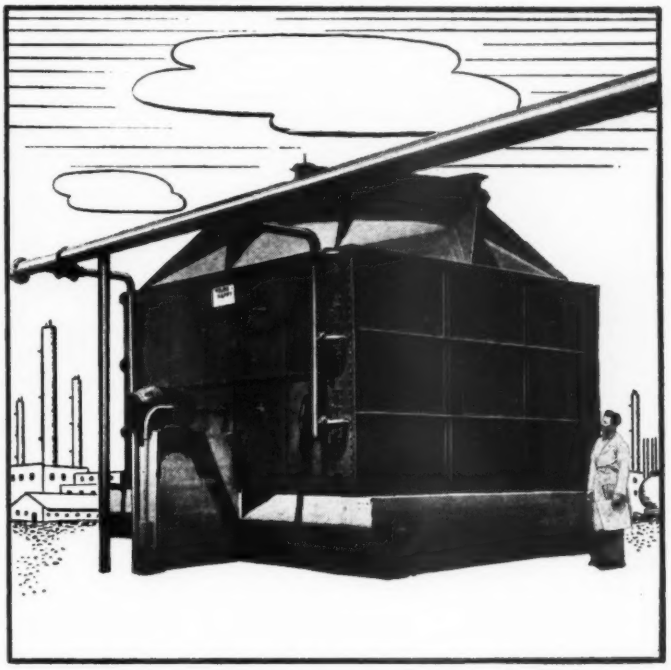
Summary of Perfo-Jet operations from October, 1947, to February, 1948.

Ref. no.	Date	Carriers			Charges		Shooting depth, ft		Fluid in hole	Temperature	Remarks
		OD, in.	Shots/ft	Runs	Type	Total	From	To			
23	11/22	5	2	9	A	108	3406	3460	Water		Bad detonator on Run 5.
24	11/24	5	2	1	A	12	3284	3290	Oil		——
25	11/25	5	2	3	A	30	3595	3610	Water		——
26	11/25	5	4	2	A	48	4686	4698	Water		See also Ref. Nos. 29, 32, 52.
27	12/2	5	2	2	A	24	3079	3120	Water		——
28	12/5	5	3	6	A	140	2840	2875	Mud		——
29	12/5	5	2	2	A	32	3981	3989	Mud		——
30	12/2	3⅜	4	1	Local	24	7044	7050	Mud		See also Ref. No. 31
31	12/6	3⅜	4	1	Local	24	7037	7031	Mud		——
32	12/10	5	4	4	A	32	3981	3989	Mud		——
33	12/4	5	4	4	A	96	2041	2079	Mud		——
34	12/10	5	2 & 4	8	A	144	5417	5518	Mud	180 F.	——
35	12/18	5	3	3	A	72	4964	4978	Mud		——
36	12/9	5	2	15	A	180	11730	11860	Mud		——
37	12/18	5	2	23	A	270	2998	3145	Mud		——
38	12/26	5	4	2	A	32	4010	4018	Mud	90-100 F.	——
39	12/29	3⅝	2	6	A	64	6550	6582	Mud		——
40	12/28	3⅜	4	2	A	48	6905	6915	Mud	130 F.	See also Ref. No. 65.
41	12/31	5	4	20	A	456	8176	8410	Mud		Two misruns—due to leaky set screws.
42	12/31 (1948)	5	2	1	A	12	1557	1563	Mud	Low	——
43	1/5	3⅜	4	4	A	48	3667	3677	Mud	110 F.	——
44	1/12	5	12	9	A	180	3254	3269	Mud	118 F.	——
45	1/16 (1947)	3⅜	2	3	A	36	4385	4571	Mud	Low	——
46	12/21 (1948)	3⅜	4	3	A	72	7677	7689	Water	149 F.	Seven misfires due to leaky seals.
47	1/13	3⅜	..	..	..	..	..	..	..	..	Unable to perforate due to well conditions. Completed in Ref. Nos. 48 and 49.
48	1/14	3⅜	4	1	A	24	3960	3954	89 lb mud	122 F.	See also Ref. No. 49.
49	1/15	3⅜	6	5	A	66	3945	3960	89 lb mud	122 F.	——
50	1/17	3⅜	4	1	A	4	2185			Low	W. S. O. See also Ref. 51.
51	1/19	3⅜	6	10	A	174	2191	2220	Mud	Low	——
52	1/20	5	4	4	A	32	3981	3989			——
53	1/20	3⅜	2 & 4	23	A	210	3600		Wtr & oil		——
54	1/17	5	4	19	A	408	5422	5504	Water	150 F.	One carrier fished due to entry of sand.
55	1/26	5	2	5	A	60	6643	6673	Oil		——
56	1/22	5	6	7	A	90	3947	4002	76 lb mud	85 F.	——
57	1/26	5	6	6	A	90	8145	8155	76 lb mud	160 F.	Two misruns due to faulty detonators.
58	1/30	5	2	21	A	246	2218	2341	Water	Low	See also Ref. No. 17.
59	2/3	3⅜	4	13	B	276	8934	9016	Oil		——
60	1/29	5	4	15	A	336	10966	11080	Oil	245 F.	——
61	2/2	5	4	5	A	120	10400	10430	Water		See also Ref. No. 68.
62	2/4	5	2	5	A	60	7900	7930	Water		See also Ref. No. 99.
63	2/5	5	2	15	A	150	4395	4485	Water	Low	——
64	2/1	5	6	2	A	12	9046	9055	75 lb mud	186 F.	Two misfires due to faulty detonators. See also Ref. No. 67 69, 71, 72.
65	2/9	3⅜	4	4	B	96	6862	6915	Water		——
66	2/3	3⅜	2	18	B	198	3050	3200	Water		——
67	2/3	5	4	10	A	240	3740	3800	Water		——
68	2/5	5	4	12	A & B	288	10315	10391	Water		——
69	2/4	3⅜	6	2	B	36	9048	9054	Water		——
70	2/10	5	2	12	A	140	5880	5950	Water		——
71	2/8	3⅜	4	1	B	4	9060		Mud		W. S. O.
72	2/10	5	4	1	A	4	9090				W. S. O. misrun due to faulty detonator.
73	2/14	5	4	18	A & B	420	6545	6650	Water		——
74	2/15	5	2	8	A & B	96	2815	2863	Water		——
75	2/15										Unable to perforate due to well conditions. See Ref. No .77 for completion.
76	2/16	5	2	7	A	80	3545	3585			——
77	2/16	5	2	3	A	30	4879	4894			——
78	2/16	3⅜ & 5	2	22	B	264	2662	2945			——
79	2/18	3⅜	2	7	B	80	5523	5563			——
80	2/17	3⅜	4	1	B	4	9090				W. S. O.
81	2/18	3⅜	2 & 4	3	B	40	4654	4668			——
82	2/18										Left carrier in hole due to well conditions.
83	2/20	5	4	4	A	96	5941	5965			——
84	2/21	5	4	26	A	300	6380	6465			——
85	2/18	3⅜	4	1	B	4	9085				W. S. O.
86	2/19	5	4	10	A	100	7545	7580			——
87	2/21	3⅜	4	1	B	4	9079	9080			W. S. O.
88	2/25	3⅜	4	6	B	144	4651	4670			——
89	2/23	5	4	6	A	60	7490	7505			See also Ref. No. 100.
90	2/25	5	4	2	A	48	1426	1438			——
91	2/26	5	2	5	A	50	1970	1995			One misrun due to faulty detonator.
92	2/25	–									Unable to perforate due to well conditions.
93	2/26										ditto
94	2/27										ditto
95	2/28										ditto
96	2/28										ditto
97	2/28	5	2	10	A	120	6640	6710			See also Ref. No. 102.
98	3/3	3⅜	2	4	B	48	10207	10230			Completion of Ref. No. 92, 96.
99	2/27	5	2	5	A	40	7900	7930			Two misruns with partially loaded carriers.
100	2/26	5	4	5	A	100	7435	7460			——
101	2/28	3⅜	4	4	B	76	4480	4507			——
102	3/2	5	2	17	A	204	6723	6870			——
103	2/29	5	6	72	A	798	4045	4250			See also Ref. No. 106.
104	3/3										Lost carrier due to well conditions.
105	3/3	3⅜	4	5	A	120	10370	10400	Mud		Completion of Ref. No. 104.
106	3/1	5	4	16	A	180	7295	7340			

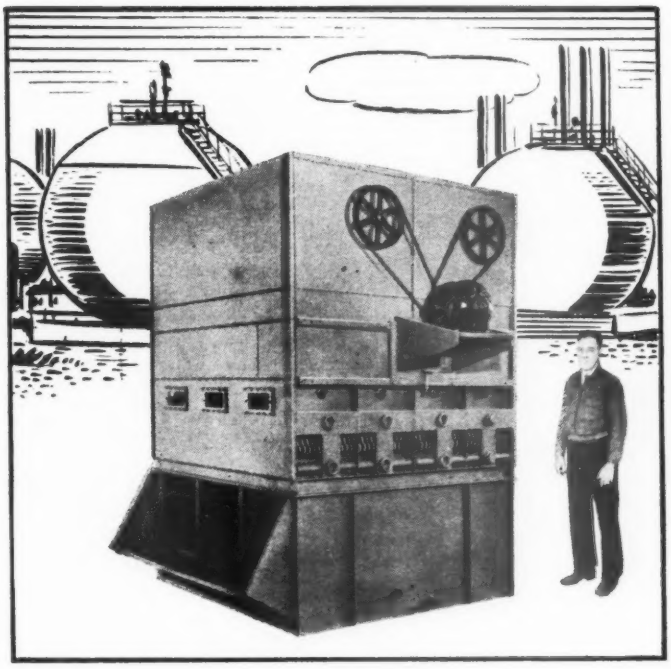
FOUR FAVORITES FOR COOLING
from Well to Refinery



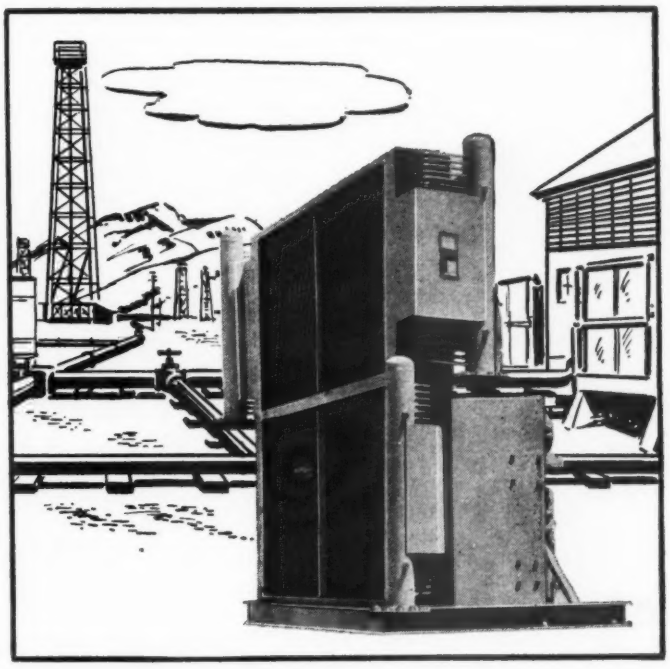
Jacket Water Coolers



Vertical Air Discharge Coolers



Evaporative Coolers



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APPENDIX II. Fields.

	Reference job numbers	Totals
Los Angeles Basin:		
Athens West	59	1
Brea	1, 6, 7, 11, 14, 18, 19, 23, 76	9
Dominguez	13, 97, 102	3
Huntington Beach	27, 91	2
La Habra Heights	17, 58	2
Lawndale	62, 99	2
Long Beach	37, 45, 77, 79, 98, 105	6
Murphy Coyote	103	1
Montebello	12, 21, 55, 84	4
Newport, West	5, 15, 28, 34	4
Race Track Hill	81	1
Richfield	53, 67	2
Santa Fe Springs	8, 9, 22, 25, 26, 29, 32, 38, 39, 52, 63, 83, 88	13
Torrance	24	1
Wilmington	4	1
Newhall:		
Newhall	61, 68	2
Shiells Canyon	78	1
Ventura	54	1
San Joaquin Valley:		
Arvin	73	1
Avenal	80, 85	2
Coalinga	2, 57, 64, 66, 69, 71, 72, 87	8
Del Valle	42, 70	2
Edison	33, 90	2
Elk Hills	16, 20, 44, 74, 86, 89, 100, 106	8
Jacalitos	35	1
Kern Front	10	1
Lost Hills	50, 51	2
Los Lobos	3	1
Midway Sunset	56	1
Oak Canyon	41	1
Paloma	36, 60	2
Riverdale	40, 65	2
San Joaquin	30, 31	2
Wasco	48, 49	2
Sacramento Valley:		
Ord Bend	43	1
Rio Vista	101	1
Texas	46	1
Colorado (open hole experimental)		1
		98

In the early stages, and while the development was proceeding, the process was available only in California on a limited scale pending the availability of additional operating equipment and facilities for quantity production of the explosive charges. In January of this year, Well Explosives, Inc., offered casing perforating service in Mid-Continent and Texas fields on a limited scale. Lane-Wells Company and Perforating Guns, Inc., have made arrangements to extend and augment the service in these areas, also in the Gulf Coast fields, in the immediate future.

At the time of writing (March 17), casing severing, opening of tight formations, and drilling extremely hard formations have been on an experimental basis. Casing severing and formation penetrating are expected to be undertaken commercially, however, in the next two months. Casing severing has been carried out in the Huntington Beach and Santa Fe Springs fields in 6⅝-in. and 7-in. casings at 3000-3300 ft depth ranges to the entire satisfaction of the oil companies. Formation penetrating has been successfully carried out in the Weber Sand of the Rangely field, Colorado. It has been demonstrated that even with 1-oz casing perforating charges, compared to 5-6-oz charges in process of development for this particular size of hole, the daily production was increased from 87 to 91 bbl per day,

The United States consumed all of the oil it produced in 1947, a daily average of 5,449,000 barrels. It sold to other nations 14,000 barrels a day more that it bought.—*The Petroleum Data Book*, Dallas, Texas.

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and, furthermore, the productivity index rose from 0.0433 to 0.0647—an increase of 48.5 per cent.

● **Casing perforating operations.** Between the end of September, 1947, and the beginning of March, 1948, Byron Jackson Company performed a total of 97 casing perforating operations on a commercial basis. The particulars of these operations are set forth in Appendix I. During this 5-month period, a total of 13,020 charges was used in 36 fields in California and one well in Texas for a California operator. In the latter operation the equipment and personnel were transported by plane from Los Angeles to Corpus Christi. The various California fields in which these charges were used are enumerated in Appendix II.

Locally made charges had been used for experimental operations from June to September, 1947. DuPont Type "A" charges were in use until the beginning of February, 1948, when this type was superseded by Type "B". Compared with the original charges, the new Type "B" provide greater penetration, a larger and more truly round hole in the casing, less burr on the inside of the casing, and considerable reduction in the size of the "slug" or "carrot".

The distribution of the various charges used on commercial operations has been as follows:

Carrier, in.	Type	Number	Totals
3⅜	Locally made	72	
3⅜	Type A	770	
3⅜	Type B	1394	2,236
5	Type A	9368	
5	Type B	1416	10,784
			13,020

Charges per operation	Operations
1– 24	14
25– 50	19
51– 75	10
76– 100	16
101– 200	20
201– 500	15
501–1000	2
Over 1000	1

Operations were carried out at the following depths for 30 companies. The number of operations for individual companies ranged from one to 26.

Depths	No. operations
Above 5,000 ft	54
5,000– 6,000 ft	7
6,000– 7,000 ft	12
7,000– 8,000 ft	7
8,000– 9,000 ft	4
9,000–10,000 ft	7
10,000–11,000 ft	5
11,000–12,000 ft	1

Details of casing sizes, weights, grades, and hole sizes are given in Appendix III, but can be summarized as follows:

Single strings ranging from 13⅜ in. to 4¾ in. (Securaloy)—74 operations.

APPENDIX III

Summary of casing sizes, weights, and grades.

Casing sizes, in.	Weight, lb	Grade	Hole size, in.	Reference numbers	No. of jobs
				Single strings	
13⅜				42	1
8⅝	40			86, 89, 100, 106	4
8⅝	36		15	16, 33, 44	3
8⅝	32	N-80	12¼	5	1
8⅝	32	C	11	15, 22, 25	3
8⅝	28	N-80	12¼	10	1
8⅝	24		10⅝	28	1
8⅝	Misc.			73, 90	2
7	32	N-80	11	36, 68	2
7	29	N-80	11	41	1
7	28	J-55	11¾	55	1
7	26			70	1
7	23	N-80	10⅝	4	1
7	23	J-55	10⅝	3, 21, 34, 67, 97, 102	6
7	23	J-55	9⅞	1, 6, 7, 11, 14, 17, 18, 19, 23, 35, 58	11
7	23 & 26		9⅞	13	1
7	20			20, 56, 57, 61, 62, 99	6
7	Misc.			105	1
6⅝	28	45-Y	10⅝	12	1
6⅝	26	N-80		8	1
6⅝	26	C	8⅝	37	1
6⅝	26	J-55	8	63	1
6⅝	26			24, 66, 77, 83	4
5¾	23	S		53	1
5¼	22½	DBX		43	1
5½	17	J-55		30, 31, 39, 46, 59, 65, 88	7
5½	15½			40, 81	2
5½	Misc.			48, 49, 50, 51, 87, 101	6
5	Misc.			98	1
4¾		Securaloy	7½	2	1
				Total single strings	74
				Double strings	
10¾x8⅝				27	1
9 x6⅝	45 & 26		12⅜ & 8¾	54	1
8⅝x7				103	1
8⅝x6⅝	28 & 26			9, 26, 74, 76, 84	5
8⅝x5¾	36 & 22½			45, 79	2
8⅝x5½	36½ & 22½			78	1
7 x5½	32 & 18		10⅝	60, 64, 69, 70, 72, 80, 85	7
				Total double strings	18
				Triple strings	
11¾x8⅝x6⅝	54, 36, 26	J-55		29, 32, 38, 52	4
8⅝x6⅝x5				91	1
				Total triple strings	5
				Grand total	97

Double strings ranging from 10¾ in. by 8⅝ in. to 7 in. by 5½ in.—18 operations.

Triple strings ranging from 11¾ in. by 8⅝ in. by 6⅝ in. to 8⅝ in. by 6⅝ in. by 5 in.—5 operations.

Carriers for jet perforator charges are either 24 or 12 charges at 3-in. or 6-in. spacing, i.e. 4 or 2 shots per ft, respectively. In a number of cases requests were received for densities of 6, 8, or 12 shots per ft, and this was arranged.

● **Field results.** In the limited period at the author's disposal for preparation of this paper, it has only been possible to obtain replies from the various oil companies covering 63 of the 97 operations performed during the 5-month period. The operations have been reviewed serially and in chronological order. It will be seen from Appendix I that Type "A" or equivalent charges were used in 62 of the 63 operations under review. This review, therefore, presents the minimum results obtainable from jet perforator charges.

Appendix IV shows that 32 of the total 63 operations were performed in zones that had previously been attempted to be perforated by bullet-type perforator. Based on replies to the author's questionnaire, as received from operators, it appears that positive results indicative of the greater effectiveness of the jet perforator were obtained in at least 15 of these 32 operations. Thirteen operations were inconclusive from a comparative standpoint, and two produced negative results. In this connection it should be borne in mind that failure to obtain paying production is not necessarily a reflection on the effectiveness of jet perforating, for it is always possible that the zone perforated is not producible. The remaining 31 jet perforating operations detailed in Appendix V were performed in zones that had not been perforated previously, and hence no comparison with bullet perforating can be made. However, it will be noted that 21 of these operations resulted in tangible evidence of having opened up the formation to the well. The results obtained on 9 were inconclusive, and on one operation the results appear to have been negative.

On the whole, these results present concrete evidence, confirmed by representatives of the various oil companies in California, that the successful development of lined shaped charges for perforating well casing is an accomplished fact, and this process can be relied on to open formation to the well, and to obtain production if the formation is producible.

The author does not wish to convey the impression that the Jet Process is completely satisfactory in the present stage of development. There are still a number of defects to be overcome, and considerable improvements will undoubtedly be made in course of time. It has been shown that even in this early stage of commercial application the Jet Process offers the industry means of

APPENDIX IV

Results obtained with Jet Perforator charges in zones previously perforated.

Ref. no.	Previous perforations	Previous production	Fluid level—Perfo-Jet shooting			Operators' remarks on results with Perfo-Jet
			Before	After	Difference	
2	Intensively shot with bullets.	Nil	Full	Full	..	"The jet perforator penetrated the cemented liner after a conventional gun perforator had failed."
3	4-½ in. holes/ft from 1504 to 1570 ft.	No trace of oil or gas after standing 48 hr.	Full	Full	..	"Estimated 50,000 cu ft of gas per 24 hr indicating a greater penetration with jet gun although less holes than regular gun."
4	Bullet	41 B/D; 28.2°; 22.0%	1485	1455	+ 30 ft	"No increased production. This well was apparently adversely affected by water block. It was hoped that the shaped charges would penetrate beyond the zone of reduced permeability. A borderline case."
8	Bullet		5220	5030	+190 ft	No advice received from oil company.
10	Bullet	Nil	1610	1330	+280 ft	"Believe jet perforating is the only way."
13	Bullet	20 B/D; 28.7°; 47.4%	4840	3860	+980 ft	"Production 12 B/D, 28.7°, 50.2%."
14	Bullet	Nil	3050	3038	+ 12 ft	"No increase after Perfo-Jet. Washer showed only seven holes open."
16	Bullet	Nil	1440	1420	+ 20 ft	"108 B/D, mostly water."
17	Bullet	Nil	1360	1290	+ 70 ft	"Well lacks fluid." See also Ref. No. 58.
20	4-⅜-in. holes/ft	Nil	1000	1025	— 25 ft	"5 B/D oil and 4 B/D water."
22	Bullet	Some	3200	?	?	"Production obtained."
25	Bullet	Some	2500	?	?	"Production obtained."
28	Bullet	Nil	380	380	Nil	"Previous gun perforations indicated nothing. Perfo-Jet indicated penetration by filling hole with sand.
33	6⅜-in. holes/ft	2.7 B/D	1625	1738	—113 ft	"Production 1 B/D. This is not a fair test of production results as sand was very poor."
35	Bullet	Nil	480	480	Nil	"No fluid came in."
36	10-½-in. & ¹⁵⁄₁₆-in. holes/ft.	Nil	Full	Full	Nil	"Approx. 300 B/D salt water obtained from zone which had previously been shot (with bullets) but which had failed to contribute water."
39	Bullet	Yes	6490	6520	— 30 ft	160 ft fluid rise but no overall increase in production.
40	Bullet	Nil	Full	Full	Nil	"No production obtained with bullets or jet perforator charges."
42	Bullet	Nil	Full	Full	Nil	Well produced in large quantity after application of pressure.
43	Bullet	Nil	Full	Full	Nil	"Perforated with jet gun through interval that had been previously shot twice with conventional gun and included 5 ft more zone. Gas production in excess of 1 MCF/day obtained. No way of determining whether jet perforations or additional zone caused well to produce but all holes in the lower 5 ft were made with jet perforator."
45	10—½-in. holes 4575-4565 ft & 4480-4490 ft.	Nil	4010	3980	+ 30	"3 B/D obtained."
46	104 bullets in 10 ft	Show on JFT	Full	Reduced	?	"No fluid inflow obtained with bullets. Penetration obtained with Perfo-Jet but results inconclusive.
51	24 rows, 2-in. x 60M 6 ft 0 in. Kobe TC	Water injection well. Injection rate—239 B/D water at 50 psi over pressure (**before** cementing).	385	385	Nil	"Re-perforated 5½-in. liner with 6—½-in. holes/ft 2220-2190 ft because original perforations were plugged with cement in order to obtain a WSO above the perforated interval. Shot holes were open but tight from 2199-2191 ft. After 9 days injection rate was 94 B/D water at 605 psi injection pressure."
52	Perfo-Jet Ref. Nos. 29 and 32.	Nil	3280	3280	Nil	"Fluid rise of 5 ft. Oil production nil."
53	408—⅜-in. bullets.	25 B/D gross	2475	2475	Nil	"Well washed very freely. Results not definitely known yet. Appears to be about 40 B/D gross."
57	6—½-in. holes/ft.	38 B/D oil, 32 B/D water	Full	38	— 38	"25-hr test of perforated interval 6565 ft water. Jet perforating considered satisfactory."
58	Yes	Nil	1360	1290	+ 70	"Well lacks fluids."
60	Bullet	Some	Full	450	— 450	"No increase in production."
62	Bullet	Nil	Full	Full	Nil	"Productive zone shut off with cement and plastic. Jet perforated interval would not wash. Subsequently reshot with jet perforator charges of latest type (b) and the zone washed freely."
63	Partially perforated.	?	4150	4210	— 60	"Well would not wash. Subsequently shot with bullets. Approx. half of interval perforated after Perfo-Jet still would not wash. Balance of zone that would wash took considerable pressure."
64	4—½-in. holes (WSO).	Nil	Full	Full	Nil	"Surged well with water at 600 psi. No fluid going away JFT indicated WSO. Jet perforating information inconclusive as far as penetration is concerned as water was apparently shut off."

Ref. no.		Date	Zone	Holes	Charge	Runs	Misfires	Duration of JFT test	Net recovery	Bbl recovery	Rate of entry
61	-Bullet	2/1	10430-10400	120	150 grms	3	Nil	1 hr 57 min	285 ft	2.08	1.07
	-Jet	2/3	10430-10400	120	28 grms	8	3	5 hr 51 min	572 ft	4.18	0.71
68	-Jet	2/5	10391-10355	144	28 grms	16	4	22 hr 58 min	2596 ft	18.9	0.825
	-		10351-10315	144	28 grms						
	-Bullet	2/8	10391-10355	34	150 grms	8	Nil	40 hr 50 min	3780 ft	27.6	0.676
			10351-10315	35							

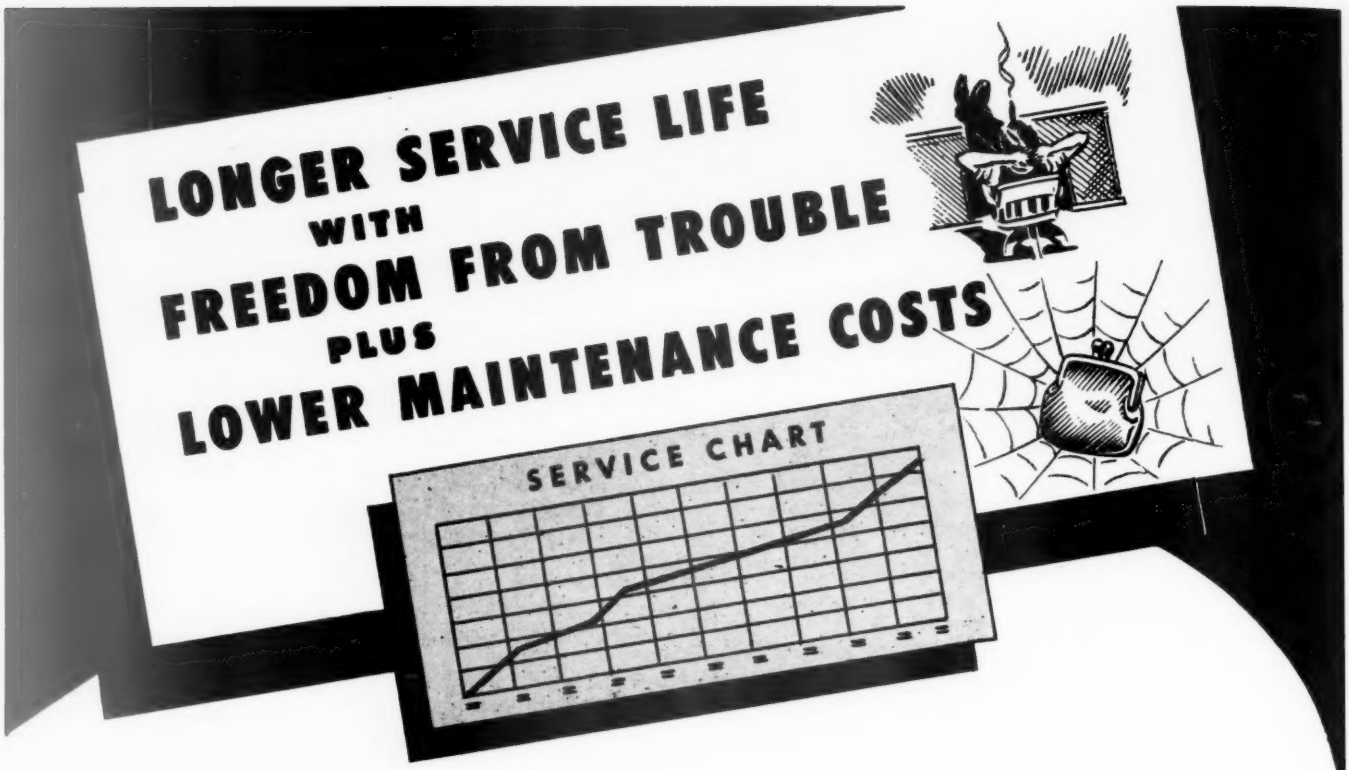
Positive results in favor of Jet perforator charges:
Ref. Nos. 2, 3, 10, 16, 20, 22, 25, 28, 36, 42, 43, 45, 53, 57, 62 15

Inconclusive results:
Ref. Nos. 4, 13, 17, 33, 35, 39, 40, 46, 51, 52, 58, 60, 61, 64 14

Negative results:
Ref. Nos. 14, 63 2

No comparative results available:
Ref. No. 8 1

32



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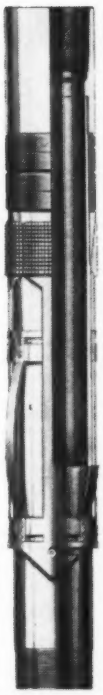

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FIG. 1

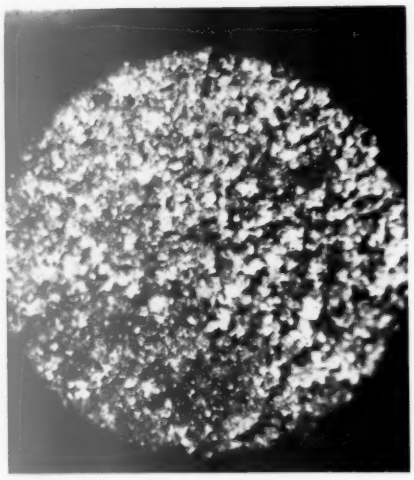

FIG. 2

FIG. 3

APPENDIX V

Results obtained with Jet Perforator charges in zones not previously perforated.

Ref. no.	Fluid levels—Perfo-Jet shooting			Operators' remarks on results with Jet Perforator charges
	Before	After	Difference	
1	4207	690	3517	"Considerable fluid entry."
5	1390	1240	150	"Discovery well."
6	3975	2855	1120	"Obtained production."
7	3548	?	?	"Increased production."
9	?	?	?	"Production obtained."
11	2990	375	2615	"Considerable fluid rise."
12	5470	5180	290	"Producting horizon twice bullet perforated. Test showed a number of tight spots. Production 22 B/D oil and 5 B/D water. Whole horizon was then jet perforated and an additional zone opened up. Production after jet perforating 88 B/D oil and 44 B/D water. Increased production considered to be from new zone."
15	Full	Full	Nil	"Production 150 B/D 15-18% more gravel required to gravel pack liner than adjacent wells shot with bullets."
18	2987	2850	137	"Some production."
19	3070	1460	1610	"Obtained production."
21	2885	1975	910	"Producing horizon had been bullet perforated. Tests showed perforations not open. Whole horizon was jet perforated and an additional zone opened up. No increase in production obtained."
23	2990	2760	230	"Some production."
24	1152	1082	70	"Production 10 B/D oil."
26	1265	1295	30	"Oil production nil." See also Ref. Nos. 29 and 32.
27	2045	2045	Nil	"Nothing came on bailing. Subsequently intensively shot with bullets in the same zone and got in mud and sand with a fluid rise of 500 ft."
29			800	"Fluid rise 800 ft. Oil production nil."
30	Full	Full	Nil	"Large entry of fluid. Successful."
31	Full	Full	Nil	Non-productive zone.
32	3490	3445	45	"Oil production nil."
34	Full	Full	Nil	"Results were uncertain because zone perforated was completed in conjunction with the liner completion of additional zone."
37	240	840	— 600	"No production obtained with jet perforator charges. The well was subsequently shot with bullets and no increase in production obtained.
38	2530	2510	20	"No fluid entered hole with Perfo-Jet. Followed with gun perforator (¾-in. holes). Pressure washer indicated holes through casing and absence of formation fluid but left doubt as to penetration of third string."
41	Full	Full	Nil	Non-productive zone.
44	1675	1635	40	"Production 18 B/D and 176 B/D water."
48&49	Full	Full	Nil	"Holes were washed and shown to be open. Formation test of gas. Gas in commercial quantities was not found."
50	445	445	Nil	WSO.
54	Full	Full	Nil	"Holes washed satisfactorily with pressure washer at 3000-5000 psi. 87 B/D oil with 1.6% cut obtained."
55	5080	5032	48	"Commercial production obtained."
56	Full	Full	Nil	"Formation test of thin oil sands separated by water sands. Penetration was obtained through the casing as determined by circulation between the holes. The interval was not produced due to the large amount of water encountered."
59	4310	3950	360	"No production obtained."

Positive results obtained with jet perforator charges: Ref. Nos. 1, 5, 6, 7, 9, 11, 12, 15, 18, 19, 23, 24, 29, 30, 44, 48, 49, 50, 54, 55, 56	21
Inconclusive results: Ref. Nos. 21, 26, 31, 32, 34, 37, 38, 41, 59	9
Negative results: Ref. No. 27	1
	31

penetrating one, two, or three strings of casing and the surrounding cement sheath. The process is free from certain drawbacks of bullet perforation to which operators have made objection on practical and theoretical grounds.

● **Effect on producing formations.** It has been reasoned by some petroleum engineers that the exposed surface of the hole made in the formation by jet perforator charges would be fused by the action of the jet. Several 3⅝-in. diam cores of the Weber Sand were cemented with neat cement inside 7-in. casing and perforated longitudinally as shown in Fig. 1. It should be noted in Fig. 1 that the area immediately adjacent to the perforation has changed from the dark brown color to a lighter shade. Micro-photographs at 30 diameters of the sand on a clean fractured surface and on the face of the perforation at point (A) is shown in Figs. 2 and 3, respectively.

Comparison of the two micro-photographs results in a first conclusion that the porous sand condition has been destroyed, though further tests indicate that this is not the case. By washing the perforation face with water and examining it with the miscroscope, a condition similar to Fig. 1 was found.

From these observations it is concluded that the velocity and shock of the jet pulverizes the sand grains, and leaves them on the perforation face. The lighter color of the perforation face is due to the pulverized sand grains. It does not seem possible that this condition could decrease the permeability of the sand since it is not a fusion of sand particles but a pulverizing action and the small particles are easily removed by fluid flow. There is no evidence of compaction such as takes place with perforator bullets.

● **Acknowledgment.** The author acknowledges the assistance of A. E. Hambly, M. B. Riordan, and W. T. Box, of Byron Jackson Company, in the preparation of this paper. Details of the work done by the Service Division of Byron Jackson Company are ordinarily treated as confidential. Permission was, therefore, requested to mention the work detailed in the appendices. Sincere thanks are expressed for the favorable consideration of this request by the oil companies, also the ready assistance and cooperation of their petroleum engineers.

* * *

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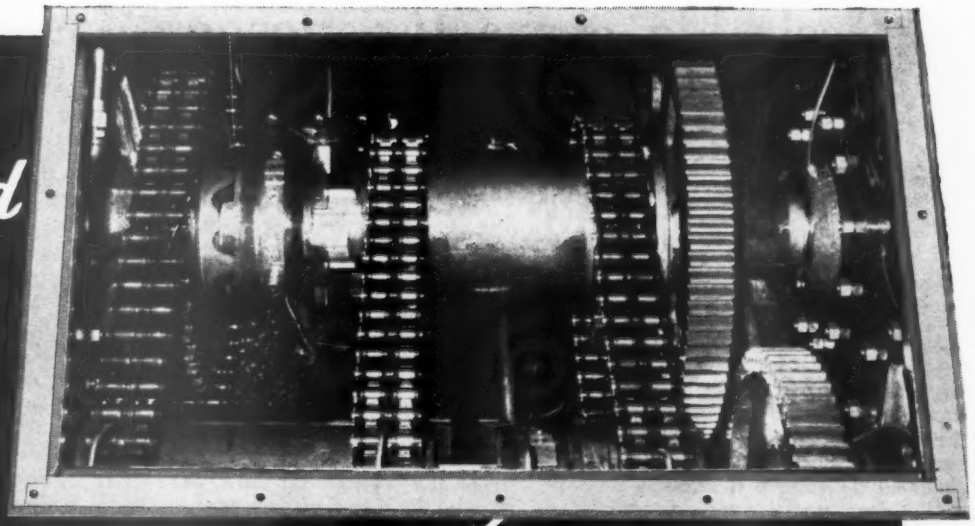

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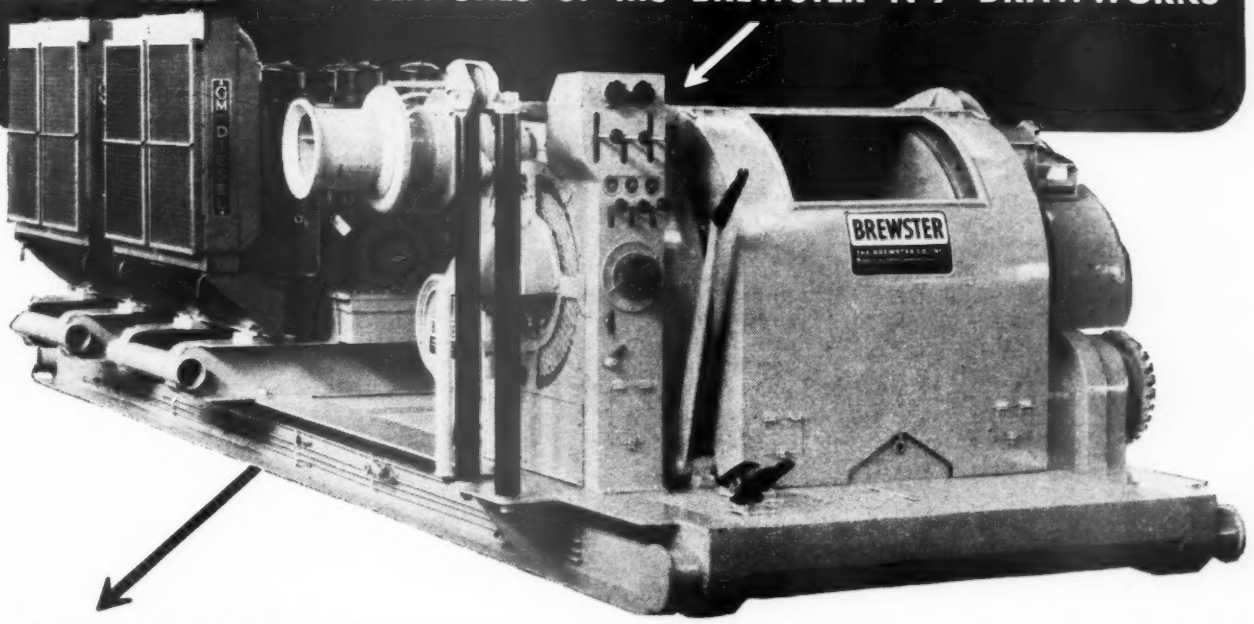

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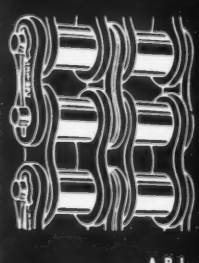

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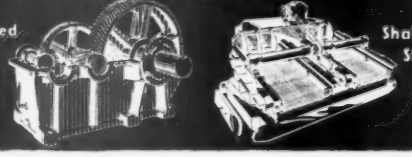

Desirable characteristics of pumping units and engines*

By J. C. SLONNEGER, Continental Supply Company

IN the normal course of development of any machine, the fundamental engineering procedure and design tend to stabilize. Of course it is very rare for an entire design to become stabilized even in simple machines, but usually certain elements do assume a likeness among all designers, and are recognized as satisfactory in both economy and function. When elements receive such universal acceptance they may be established as standards. Such is the normal development of standards. Sometimes the process is reversed; that is to say, the standardization of an element precedes and dictates the universal design.

Much of the standardization sponsored and adopted by the API for pumping units falls in this rather unusual class. The application of the gear and chain reducers to oil well pumping in general, and then their application to the unit pumper, was so rapid as to cause an extraordinary amount of confusion. The API deemed it wise to force the normal process of standardization. The excellent results obtained unquestionably declare the wisdom of that decision.

Up to the present, the API has adopted a standard method of rating gear and chain unit reducers and also a number of definite sizes. The operator of a unit reducer bearing the API name plate is assured of a very definite minimum capacity in each size of unit, and the manufacturer is freed from the unnecessary expense incurred in providing unneeded sizes to the market. By API standards, unit reducers are rated in capacity on inch-pound torque instead of an average horsepower. This in itself revolutionized the application of unit reducers and eliminated much of the confusion of previous reference.

Beyond the method of testing and rating pumping engines, the API has done very little in standardization for engines. Unfortunately, the method of rating engines as adopted by the API neglects to give any consideration to flywheel size, and its effect on engine rating for oil well pumping. We shall discuss this a little later.

Standardization has many desirable advantages, but it also has its limitation. It is sometimes difficult to decide where standardization should stop and where the ingenuity of the designer should be given its full scope. Too much standardization halts progress and brings on decay, whereas too little standardization breeds chaos. Of course, that which is capable of definite proof, or that which has been proved can, and should be, standardized. But all design is not capable of definite proof. Under those circumstances, standardization may go only so far and as fast as good practice is generally recognized and accepted. When the need of standardization is great and very apparent, it is often wise to take the risk of error by forcing standardization. We pick the plum a little green, so to speak, and let it ripen on the shelf. By doing so, we change the standards slowly to fit the progress, yet the standards thereby direct progress in an orderly fashion, and increase the rate of progress. Thus we reach the same end result, but with a minimum of time and confusion.

What remains to be standardized in pumping equipment, and why the delay, is good for a long argument any time two or more experienced men get together who have to deal with oil well pumping. Why all this confusion? The problems involved in oil well pumping are complicated, and involve a great many factors that are not generally well understood, all of which is confusing.

As is the case in all engineering, the most difficult problem is to state the problem accurately. Too often we solve a problem rightly only to find we have solved the wrong problem. We did not state the problem rightly to start with. The right problem may not have been any more difficult to solve than the wrong one, but we are led astray because we fail to state our problem rightly. In the following discussion I propose to show some common errors in stating the diverse problem involved in sucker rod pumping.

The fundamental problem in sucker rod pumping is to deliver the desired quantity of fluid from the bottom of well to the tank, with the greatest economy and least effort. There is no argument about this, for it is precisely this that we are all striving to do. The next problem is to force the plunger and its cylinder to have a relative reciprocating motion. Where the distance from the crosshead to the plunger is quite short, as in a common power pump, no serious problem is involved, but when the piston rod, commonly called sucker rods, is lengthened to any length from 1000 to 7000 ft, we are confronted with an entirely different and quite complicated problem. The motion imparted to the plunger is no longer identical with the motion of the crosshead, commonly called the rod hanger. The stretch of the sucker rods becomes of such magnitude as to seriously and appreciably change the motion of the plunger with respect to that of the rod hanger. Some writers upon this subject have taken the stretch of the rods due to load into consideration, and have shown that the most fluid will be pumped if the stretch of the rods due to load on the plunger is one-half the stroke length. But that is not true, because those writers solved the wrong problem rightly. It is true that rods stretch due to a static load, but that is only half the truth. The other half is that rods also stretch due to their own intertia.

I choose to call the static stretch, static resilience, and the stretch due to inertia, dynamic resilience. The spring constant, (that is, that force as measured at the polish rod to produce 1 in. of stretch) I choose to designate K_1 for dynamic resilience and K_2 for static resilience. For a straight string of rods (rods all of one size): $K_1/K_2 = 2$

For tapered rod string the ratio of K_1 to K_2 has some value other than 2, but that value can never be equal to one, hence K_1 and K_2 always differ.

As the rod string possesses both mass and resilience, it must have a natural frequency of vibration. Hence, we not only have a rod string that may stretch in two different ways, but we also have one that is subject to vibration. As a corollary to this, we may say: Since there is no known way whereby a force may be transmitted from one point to another without the lapse of time, a definite period of time is required to transmit a force from the polish rod to the opposite end of the rod string. As the solution of this problem has enough material in it for several papers, its solution is beyond the scope of this paper. It is pointed out here to show that in selecting pump sizes, rod sizes, speed and stroke length most operators have been solving the wrong problem rightly with some very confusing results. That all this is actually true is evidenced by the many curious and sometimes fascinating shapes of the dynagraph taken at the polish rod, and which are wholly unexplainable except by the application of the abovementioned properties of sucker rods.

It is interesting to note that the theory of sucker-rod vibration was first discussed in 1937, and recently has gained some acceptance and application. The application of rod vibration and the dynamic and static spring contents to dynagraph analysis was published in Bulletin No. 230, Proceedings Twenty-fourth Council Meeting of the API 1943, as a discussion of well loads. I don't think it has been much used except by its author. In addition to this, there is a host of other factors, such as gas-oil ratio, bottom-hole pressure, tubing stretch, etc., that produce their full effect upon the dynagraph. But these factors are of a secondary importance. We must first state and solve the sucker rod problem rightly before we can predict or detect the effect of these secondary factors. In passing it may be well to point out that sucker rods have been standardized by the API to a satisfactory degree, and little needs to be done other than keep the standards even with normal progress.

*Presented before the Spring Meeting of the Mid-Continent District American Petroleum Institute, Division of Production, Wichita, Kansas, March 25-26, 1948.

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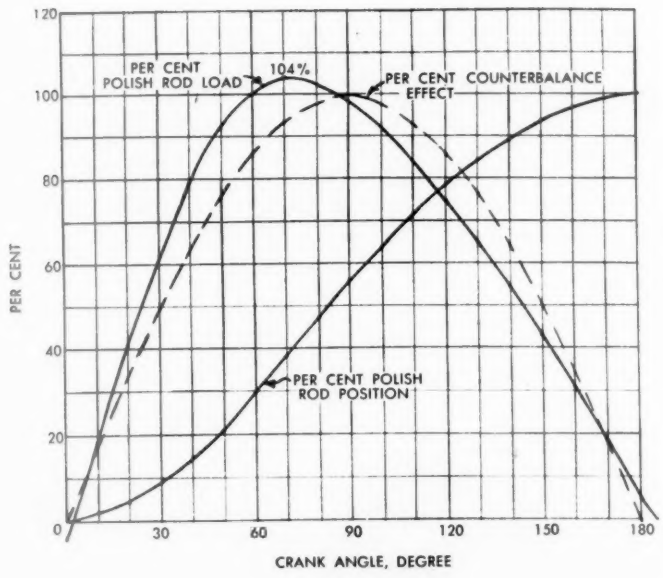

FIG. 1.

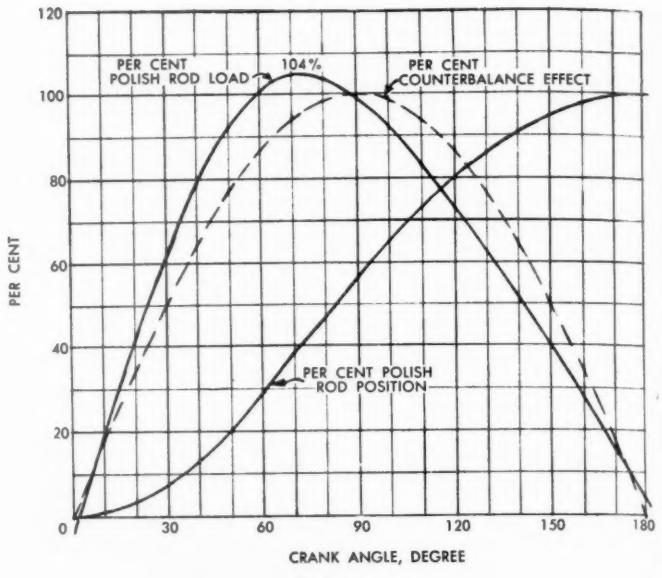

FIG. 2

(Counterbalance curves in Figs. 1 and 2 are for rotary counterbalance only)

There is a possibility that the API standardization on pumps has been carried too far, and to some extent are being ignored because they handicap design. This undoubtedly will be corrected in time.

The instantaneous load at the polish rod as recorded on the dynagraph produces a force at the crankpin of the unit reducer, which in turn produces a torque at crankshaft of the reducer. The numerical value of that torque depends very much upon the geometry or proportion of the unit pumper elements. At the present moment, there are no standards on the proportions or geometry of unit pumpers, with the result the torque effect of a given polish-rod load and circumstance varies greatly in the current designs. An attempt was made to standardize the geometry of unit pumpers, as disclosed by J. R. Mahan in Bulletin 231, Proceedings Twenty-fifth Annual Meeting API 1945. In my opinion it was most unfortunate that the committee rejected the proposal. However, several manufacturers agreed to offer, and are now offering, unit pumpers to the trade having the proposed geometry.

To obtain the value of the torque at the crankshaft of the reducer due to polish-rod load, we may plot a series of curves from the geometry of the unit pumper, such as is shown in Fig. 1. The load factor curve is plotted against the crank angle such that the polish-rod load multiplied by the stroke radius and that product multiplied by the factor give the torque in inch-pounds due to the polish-rod load only. Also a second curve shows the counterbalance factor plotted against the crank angle position such that the counterbalance in inch-pounds at its maximum value (that is at the 90-deg position) multiplied by the factor from the curve give the counterbalance effect in inch-pounds for any position of the crank. A third curve shows the polish-rod position in per cent of its total stroke plotted against the crank angle. It will be noted that the counterbalance factor is a simple sine curve or simple harmonic motion. The difference between it and the polish-rod load factor curve incidentally shows the deviation of the polish-rod motion from simple harmonic motion.

The curves in Fig. 1 are for a horsehead or wire line hanger type unit having these geometrical proportions:

Working center of the well end of the walking beam equals 1½ times the maximum stroke length.

Samson post height equal 2½ times the maximum stroke length plus 6 in.

Fig. 2 shows similar curves for a beam hanger type unit pumper. The curves are almost identical with those of Fig. 1, but to achieve this almost identical result the geometry had to be altered. Here the working centers of the well end of the walking beam is two times the maximum stroke length.

After careful study the men sponsoring this geometry of the unit pumper concluded that these proportions achieved the best overall results consistent with economy and practical results. To decrease these proportions for the purpose of reducing first costs could not be justified because of further serious distortion of polish-rod load factor curve, causing overload on all parts including the unit reducer, whereas increasing these proportions added to the first cost without much improvement in the performance curves. In other words, the law of diminishing returns becomes effective. There is a real need for this standardization, and it is hoped that the API will soon adopt such a standard. Anyone who has taken the time to analyze the unit pumpers now offered to the trade will find some with very bad geometry, which produces an unsteady motion at the polish rod, and those units are difficult to counterbalance properly, thus producing unnecessary and destructive forces throughout the entire mechanism from the source of power to the standing valve.

The unit pumper is only half of the problem after we leave the sucker rods. The prime mover is the other half. The prime mover may be either an internal-combustion engine or an electric motor. I have elected to discuss only the internal-combustion engine as a prime mover for oil well pumping with sucker rods. In order to attack the problem, let us first state it.

1. The engine must overcome a widely fluctuating periodic load, whose peaks may be as much as 3½ times the average load of the period.
2. As simple harmonic motion is reciprocating motion produced by the least possible maximum force for a given frequency and amplitude, it follows that the prime mover should run at a nearly uniform speed, so as not further to distort the polish-rod motion.
3. The engine should have a wide range of speed, so that the operator may adjust that speed to meet the changing well conditions, and the engine should maintain that speed day in and day out at the will of the operator.
4. The engine should be well enough constructed to operate 24 hr per day under full rated load.
5. It should be as simple as possible with a minimum number of parts so disposed as to be easily accessible when they require replacement or attention.
6. An engine should be easy to start, should start promptly, and should be easy to service in its routine operation.
7. The engine should operate equally well in winter or summer, and under partial loads. A new well usually requires very little power, so that an engine may be required to operate under light loads for a rather long period of time, before the well becomes heavy.

That is a good-sized order. Obviously, we cannot get an engine to meet all these requirements, off of the shelf. There is a definite need for a specialized design to meet these exacting requirements. Let us take them one by one.

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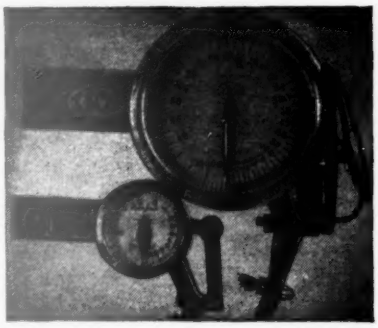

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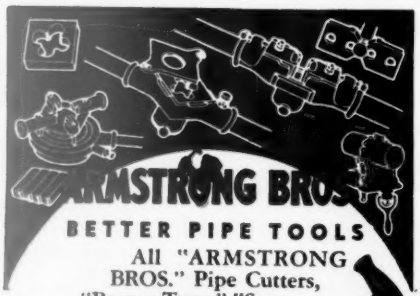

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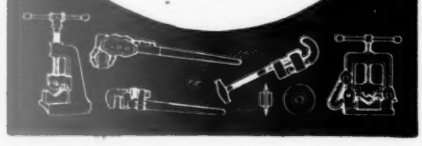

the governor can change the throttle only after the speed changes, and the engine can change its power only after the throttle changes. To maintain a constant speed under a fluctuating load by the throttle alone the governor would have to anticipate the load. If it were possible, it would still be undesirable since the throttle would have to function from closed to wide open position twice each cycle, and the engine would have to have a peak horsepower equal to 3½ or 4 times the average horsepower actually required. It can be accomplished by giving the engine a large flywheel so that by taking a 5 per cent drop in speed the flywheel will give up sufficient energy to pass through the high peak requirement and the engine can restore this energy to the flywheel during the period when less than average power is required. It has been found that 5000 ft-lb of energy stored in the flywheel per hp at maximum rated speed and horsepower will give the desired results. The flywheel must be on the engine where it reduces cyclical variation and is cushioned by the resilience of the belt drive to the unit reducer. The heavy flywheel has gained much recognition.

The heavy flywheel meets the second requirement of reasonably uniform speed provided the governor does not hunt due to the unsteady load and the 5 per cent change in speed. The governor should be damped to hold the throttle steady for the short period of time in which the speed varies from the average. At the present time this idea is still an innovation, but it works.

A damped governor can be made very sensitive without causing it to hunt, so that once set for a given average speed the governor will hold that average speed indefinitely. Unfortunately, many engines now in use for oil well pumping have only a "top speed" governor and the operator sets a throttle in a fixed position to obtain the desired pumping speed. That is in an engine taken off the shelf, probably designed for some purpose other than oil well pumping.

For 24-hr operation an engine must be generously designed. Fundamentally, no engine can be better than its crankshaft. For 24-hr service under full load the engine must have a rigid crankshaft that maintains its alignment under stress within an increment less than the thickness of an oil film, and sufficiently rigid to avoid criticals that a heavy flywheel might induce. A heavy flywheel needs a more rigid shaft than a light flywheel. Incidentally, the heavy flywheel permits the engine to put out its full rated horsepower on a pumping well, because it prevents the closing of the throttle since it does not overspeed. The API method of rating engines does not recognize this in its standards, and recommends that an engine be applied at 65 per cent of its maximum output. With a heavy flywheel and its rigid crankshaft, we may restrict the inlet manifold so that the engine cannot be overloaded and then apply it at its full rating with the restricted manifold. We do not apply electric motors at all they can pull, we restrict their output by overload relays and fuses. It makes sense to restrict an oil well pumping engine to prevent overload. The remainder of the engine must be designed generously to function under severe conditions. It must not be designed to meet a price.

Up to about 30 hp, the simple cylinder horizontal engine offers the greatest possibility in simplicity and accessibility. It also is well adapted to carry the necessary heavy flywheel. Above 30 hp the single cylinder horizontal engine becomes too cumbersome, and unwieldly.

An engine should start easily and promptly. Automatic starting on small engines is not important if the engines have been properly designed. In the larger engines automatic starting is still not what it should be. We are in need of more thought on that subject. Moreover, we eliminate many startings if we arrange to add oil and water without stopping the engines. With such an arrangement, an engine may run 30 days without stopping, and hence without starting in that interval. We have not yet found a way to change oil in an engine without stopping it.

Vapor or steam cooling has solved the problem of operating under wide ranges of climate and load. Vapor cooling holds the engine at the boiling point regardless of extraneous temperature or magnitude of load. Vapor cooling is easily applied to the horizontal engine, but is complicated and next to impossible to apply to a vertical engine.

I have tried to show that applying any type of engine, say 10 hp to a "10 horsepower" unit pumper to pump a well requiring 10 hp, is also solving the wrong problem rightly. It does not work that way.

To connect the engine to the unit reducer we need some kind of a belt drive. Now if we wished to solve the wrong problem rightly we would put a 20-hp belt drive on a 20-hp engine. We have learned, however, that the belt drive must be able to handle the peak torque of the unit reducer. Actually, that is still not the whole problem. The belt drive should be checked for the tuning of the system to avoid critical torsional vibration. Much trouble comes unsuspectedly from this source.

Where the given setup is likely to be duplicated many times such calculations on selection of a drive are worthwhile.

Many engine parts have already been standardized by the Society of Automotive Engineers, and need no further standardization by the API; however, I do believe there is need of establishing some standard of performance of engine on pumping wells. It would appear that some minimum requirement for the stored energy in flywheel per full rated horsepower would be of great benefit to the user.

Also some minimum of governed speed range in a pumping engine would pay dividends if established as a standard. You will observe I use the term "minimum." for I wish to leave as much as possible to the skill and ingenuity of the designer. If the designer can exceed the standards, all well and good, but the standards should be high enough to exclude the clumsy and the frauds. ★ ★

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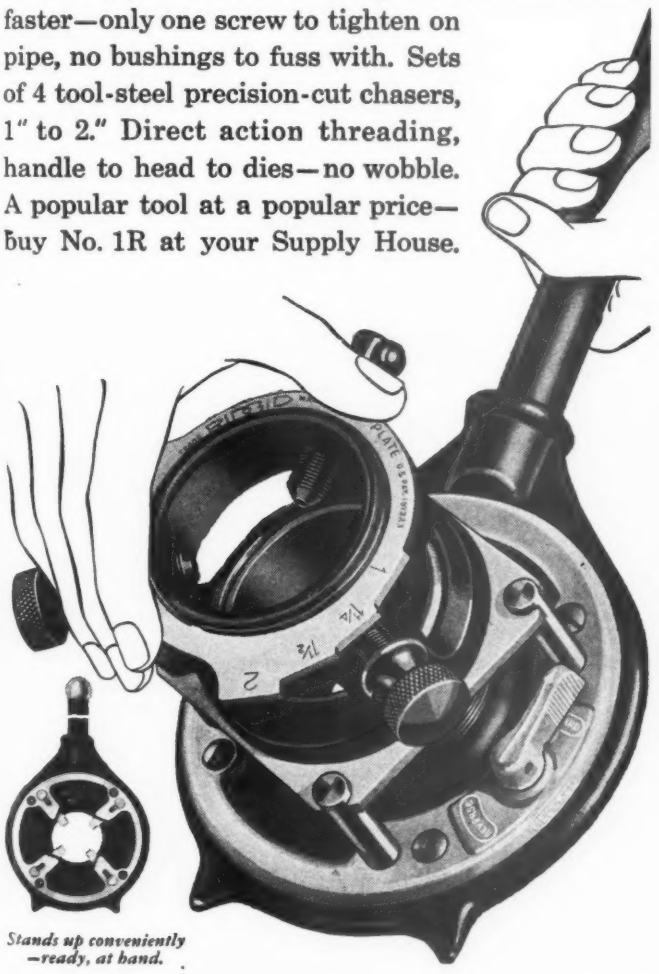

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The formation and operation of cooperative projects in secondary recovery*

By D. V. CARTER, Magnolia Petroleum Company

● **Abstract.** The formation and operation of the cooperative type of secondary-recovery project has been commented on, and reasons have been cited for this type of organization having come into existence. Such projects have played, and will continue to play, a very important role toward increasing the ultimate recovery of oil and attendant operators' profit. Cooperative agreements among secondary-recovery operators have gained their largest general acceptance during the past 20 years. They came into being because they are the simplest mechanism by which a unified effort can be achieved—simple even to the point where no formal organization or agreement implemented the enterprise. Cooperative agreements differ from other mechanisms, such as pooling and unitization, in that they allow each operator to retain title and operation of his leases. Maintenance of equity is assisted by conducting operations in the manner prescribed by agreements.

There are four essential types of cooperative secondary-recovery agreements now in general use: (a) multiple committee; (b) single committee; (c) letter of agreement, and (d) verbal agreement. Examples of agreements are given in the appendix. A partial list of fields that have, or have had, cooperative secondary-recovery projects also appears in the appendix.

Joint or cooperative operation has many advantages over ordinary operation, one of the most important being the opportunity for combining a variety of experiences and opinions for mutual benefit—a situation which also tends to dispel misunderstandings and suspicions. The cooperative type of project may be considered as an evolutionary improvement toward unit operation. On the other hand, cooperative agreements also have a number of disadvantages, most of which are eliminated in unit operation.

● **Introduction.** Cooperative action on the part of oil producers involving secondary-recovery operations is believed to be relatively old in the industry. A search of the literature fails to reveal or establish with certainty the first instance of intentional cooperation on the part of operators in this phase of production operation. The writer would hazard a guess that few formalized cooperative secondary-recovery projects were attempted prior to some 20 years ago other than, figuratively speaking, conversations "over the back fence." The use of cooperation in secondary-recovery operation for the mutual benefit of the operator, royalty owner, tax authorities, and the nation reflects the growing realization on the part of operators concerned that the maximum recovery of oil, and that full profit, could not be attained without due regard to the efficient utilization of induced extraneous energy into a common reservoir.

The fact that in a common reservoir several operators individually cannot operate indiscriminately without cognizance of the sound and common objectives of achieving a greater ultimate recovery and a larger ultimate profit means that oil producers learned the true meaning and full import of isolationism long before the twentieth-century politician.

The scope of this paper is limited to the formation and operation of cooperative secondary-recovery projects, why they came into existence, their common form and organization, their advantages and disadvantages, and legal aspects.

● **Historical background.** Carll[1] is generally acknowledged as being the first to suggest formally that water flooding might prove beneficial toward increasing the recovery of oil. In 1880 he stated:

"The flooding of an oil district is generally viewed as a great calamity; yet it may be questioned whether a larger amount of oil cannot be drawn from the rocks in that way than by any other, for it is certain that all the oil cannot be drawn from the reservoir without the admission of something to take its place.

"If one company owned all the wells drawing upon a pool, and had accurate records of the depths and characteristics of the oil-producing stratum in each well, it is quite possible that some system might be devised by which water could be let down through certain shafts, and the oil forced toward certain other shafts where pumps were kept in motion, and thus the rocks be completely voided of oil and left full of water. As it is, however, no systematized plan of action can be adopted. The careless handling of one well, by which water is let down to the oil rock, may spoil several others belonging to different parties. A clashing of interests at once arises, and is likely to result in disaster to the whole district."

Thus we can see that Carll was well aware of the fact that such a "plan of action," as he called it, would necessitate at least a cooperative effort by the "different parties" to prevent a "clashing of interests."

I. L. Dunn[2] is generally credited with having sponsored and placed in operation the first commercial air-gas injection project. It is known that deliberate "wildcat" attempts were made prior to 1900 on the part of operators to inject water into oil reservoirs. Some of these early efforts were reported to have shown beneficial results.

A goodly portion of the 88 years since Drake's well elapsed before producers exhibited an outward interest in the common problems of secondary recovery. Cooperation among them ushered in a new era. Starting with verbal agreements, a modest beginning in cooperation was established. The industry now makes use not only of numerous cooperative secondary-recovery projects, but has advanced to the point where unit operation, a more rigid form of cooperation, is gaining employment in oil- and gas-producing operations.

Cooperation has emerged in another very important form, viz., the cooperative type of engineering committee.[3] Such committees have proved to be of great value in the collection and dissemination of vital factual engineering, geological, and statistical data. This type of organization may include the activities of one or more fields, areas, or even a state. Their existence is undeniable proof that common production problems, among them cooperative secondary-recovery projects, require mutual consideration and cooperation, and is so realized by the operators.

With reference to the growth and development of improved oil-production technique, the following is quoted from an unpublished report by the writer:[4]

". . . The attempt in the later life of a field to reactivate its fecundity is commonly known as secondary recovery; a better and more descriptive term might be applied such as 'missed opportunity recovery.' The fact that steps must be taken to recover oil which otherwise would not be obtained from the reservoir is *prima facie* evidence that the field in question has not been properly operated in the so-called primary life, or to the time that requires either abandonment or rejuvenation technique.

"Resorting to the use of 'secondary-recovery' methods after primary operation represents a normal evolutionary process of thinking, developing, and application of workable ideas. It was only natural that efforts to recover oil from the 'tailings' would first be tried on fields that were considered to have less value than new or relatively new fields. In other words, it was too dangerous and risky to subject a new field to the, shall we say, dubious and uncertain experiment of injecting water into one of its reservoirs when the appearance of water in a well or field since the inception of the industry was more to be feared and considered as a definite token of ill omen

*Presented to a division of production group session on secondary recovery, before the Twenty-seventh Annual Meeting of the American Petroleum Institute, Chicago, Illinois, November 12, 1947.

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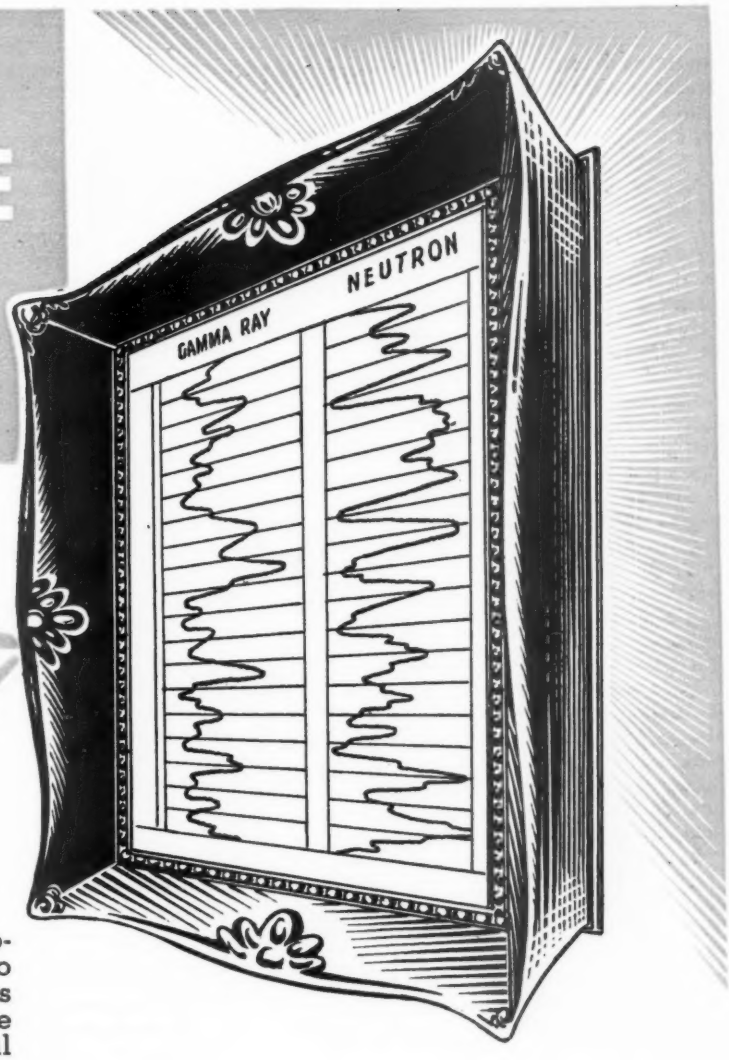

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and to presage an early end of producing operations. . . ."

"As necessity is often the mother of invention, within the past six years operators have deliberately injected water into the oil reservoirs of new oil fields with the avowed objective of maintaining to a high degree the original reservoir pressures throughout the productive life of such oil reservoirs.

"The technical advantages of such a program are many. The economic advantages are of such magnitude, in cases where water injection is feasible, that in many cases what would have been a nondescript operation with mediocre profit possibilities under normal operations, so far under water-injection programs, have indicated recovery increases in excess of 100 per cent. In addition, indications are that such recoveries will be obtained in far fewer years, and all or a far greater percentage of the oil will flow rather than require the use of artificial lift. All of this adds up to the conclusion that more and more fields, immediately upon definition of their productive limits, will have to be attended to by the early and adequate use of water injection.

"Contrary to what one would ordinarily think, early water injection does not always require unitization of the separate leaseholds in a field, although unitization is always desirable. Unitization eliminates for the most part allocation difficulties."

Successful water injection is being carried on in the Midway and Magnolia fields in Arkansas without communitizing the oil-producing properties. In each case, water is injected immediately beyond the productive limits through four injection wells. The water-system equipment in both fields is communitized. The only difference between the two is that the operator of Magnolia field project, the Carter Oil Company, distributes the capital investment and certain other expenses on an acre-foot basis. The cost of operation is borne only by those operators producing salt water, each one's share of the operating cost being determined by the quantity of water handled by the system. The Midway project, operated by the Barnsdall Oil Company, has the capital investment and operation expense both distributed on an acre-foot basis.

All this is in the way of reviewing the reason for secondary-recovery operations having come into existence. The reason is simple, viz.: greater oil recovery, generally speaking, permits increased profits. Increased recovery is also desirable for a number of other reasons, not the least of which is national defense and a higher national economy.

Why did the cooperative project come into being? The cooperative project came into existence because it represents the simplest plan for joint effort, and it is easy of accomplishment. In its more rudimentary form, it does not require any formal organization, charter, agreement, articles of organization, committee or committees. In fact, only a back-yard conversation, so to speak, suffices to initiate and carry on a cooperative project.

As time passed and safeguards were made and devised in the way of contractual instruments, committees were created, "red tape" was added and, in general, all the accouterments common to group effort were employed. Despite these refinements, there will always be room for sincere expression and exchange of opinion on the part of all of those engaged in such activities. "A word given is a promise made" could very well be the creed of the participants in this type of activity.

Management did not embrace the new idea of cooperatives too quickly, some few years ago when cooperative action between operators was first broached and before Doherty proposed the unit plan. Consequently, considerable hiatus on the part of management occurred at the outset of such activities. Perhaps this was due partly to conservatism, a habit born of long and vigorous individualistic action. After a reasonable trial period, management has tried and found that cooperation does pay in producing activities. In fact, management can, and does, keep pace by ready consideration and prompt action, and is now a co-partner of the technical man in such matters.

● **Legal aspects of cooperative projects.** It is necessary to comment on the relationship of various joint ventures which include pooling, unitization, and cooperative projects. R. M. Myers[5] has this to say:

"A joint venture is an undertaking by two or more persons to accomplish a common purpose. Pooling, unitization, and cooperative projects are all joint ventures, differing widely in their character. 'Pooling' refers to the consolidation of small tracts, usually only sufficient to constitute drilling or proration units; whereas 'unitization' refers to the consolidation of all leases in a field, or a substantial portion thereof. Projects involving the cooperative development and operation of the field differ from pooling or unitization in that each operator in the cooperative effort retains the title and the operation of his own tract or lease. Though each agrees to develop his tract in accordance with an agreed plan, the disadvantage of these cooperative efforts lies in the diversity of ownership in the field and the existence of property lines, thus limiting the effectiveness of the operation for fear of drainage between tracts."

A successful cooperative project requires a high degree of cooperation on the part of the operators involved. The principal obligation of the operators is to see that equity is achieved for their respective lessors. Another important obligation on the part of the lessee is that production must be maintained on each separate leasehold as in case of normal or ordinary producing operation, usually provided for by terms of the lease.

The principal common objective of the operators in resorting to the cooperative form of operation is to increase the ultimate recovery of oil, which normally means a greater profit for the operator and larger returns for the royalty owner. In this respect, the operator and the royalty owner are partners, at least in hope. For that matter, participants in complete units have the same objectives. Legal questions relating to modifications of the customary lease forms, reasonable development, and drainage and regulatory approvals are extensively discussed in legal literature published in 1946.[6]

With respect to fear of anti-trust violation of cooperatives or unitization, Myers[7] states:

"Fear of prosecution under the federal and state anti-trust laws has been, in some cases, advanced as a reason for not entering into unitization agreements.

"As a general rule, we believe it may safely be said that the activities of operators under a unit agreement, confined to the purposes above-mentioned, cannot be considered as cooperative activities forbidden by these laws. The activities that have been condemned have to do with prices and the restrictions of production for the purpose of limiting competition. The regulation by agreement of the output of plant, etc., is sometimes used as a means of suppressing competition and, as such, is condemned. However, it has been held in Texas that restriction of production by allocation and by limitation to market demand is a valid exercise of authority by the railroad commission, and the restriction of production under the police power has been upheld generally. It would seem that, if the operators in the unit would carefully avoid discussions of prices or the restriction of output for any reasons except the legitimate purpose of conservation, then there need be no fear of prosecution under the anti-trust laws of the state and nation.

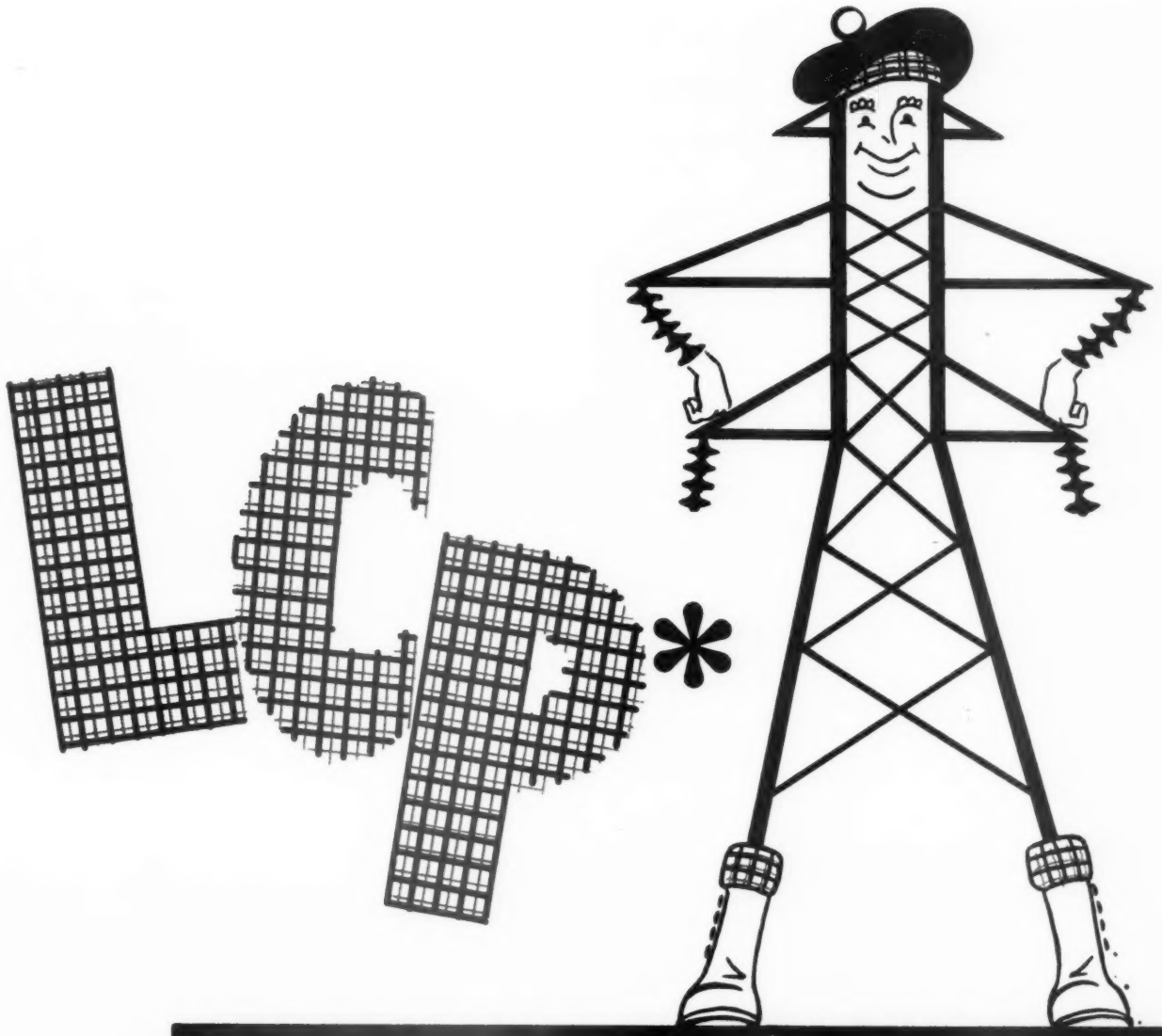
". . . These objections have, in some cases, been based on a real fear of prosecution, and in other cases have been advanced for selfish reasons. Legislation, both state and federal, which would exempt these activities from the purview of the anti-trust laws would, therefore, be a great encouragement to the creation of more units for the purposes here discussed. This has been done in Mississippi by a statute to the effect that these agreements do not violate the anti-trust laws of Mississippi when such agreements are approved by the State Oil and Gas Board.

"Parties to such agreements will, of course, not be protected simply because they have reduced their purposes to writing, if, as a matter of fact, in their meetings, discussions, and activities, they make use of their association to violate the law."

The present attorney general of the United States has recently made extensive public statements to the effect that cooperative secondary-recovery producing operations or "any activity which is necessary or essential to the conservation of natural resources or to the prevention of waste" will not be attacked under the federal anti-trust laws.[8, 9, 10]

● **Organization and operation.** A number of types of agreements and organizations are being used for various cooperative secondary-recovery projects. They range all the way from a composite organizational setup to a verbal "gentlemen's agreement," each one designed to suit the individual circumstances.

Virtually all cooperatives fall within one of the following classifications:



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1. Multiple committee — may be composed of:
   a. Management or executive committee.
   b. Operating or field committee.
   c. Legal, geological, engineering, or other special-function subcommittee or committees.
2. Single committee—operators' representatives or owner-operators.
3. Letter of agreement or contract.
4. Verbal understanding or agreement.

Specific and general examples of the multiple committee, the single committee, and the letter-of-agreement type of cooperative project, respectively, are included in the appendix; also a table showing a relatively complete list of cooperative secondary-recovery projects that are now, or have been, operating in the United States, and a list of general references on the subject.

The operation of the first type of organization, the multiple committee, requires at least two committees, viz.: a management or executive committee, and an operating or field committee. The former is generally superior to the operating committee. In some cases the subordinate group may be called an engineering committee, in which case it functions in the dual capacity of handling operating and engineering problems, and its membership is composed of at least a majority of technical personnel. As a rule, if the project requires it, an engineering subcommittee is usually created to function either under the sponsorship of the operating committee or, less rarely, under the guidance of the management or executive committee. In either event the engineering subcommittee's function and responsibilities are the same, viz., to report and recommend on technical problems and procedure. In like manner, legal, geological, or other special subcommittees may be formed as needed.

Usually it is specified in the operating agreement or in the articles of organization that a group may, upon proper approval, employ, if necessary, paid help and possibly employ outside technical assistance. The chairman is usually provided with the authority to appoint special subcommittees whose duty is to study and report a suggested course of action on some problem or matter germane to the success of the project. The committee may see fit to purchase and install community facilities. Usually provisions are included in the articles of organization, or in the operating agreement, as to the distribution of costs for community activities of the project.

Community activity costs are almost invariably distributed on the same basis as the voting strength of individual operators. Voting participation may be on the basis of acre-feet of pay, number of wells, daily production as of a given date, cumulative production of property as of a given date, or a combination of these and any other factor that the operators mutually agree is fair. One or several of the member operators may be designated as service agents to operate compressor equipment or to perform other communal services for the project. A provision is usually made in the contractual articles for the liquidation and distribution of any joint assets when the project ceases to function.

The single committee's functions include all matters relating to the particular project. It is solely responsible for the cooperative efforts of the operators.

The organization of the multiple, as well as the single, committee is usually comparatively simple. Their memberships are generally made up of owner-operators and representatives of larger operators. Representatives of major companies are usually engineers, supervisors from the production department, and occasionally a geologist or landman. The functions of each committee are under the leadership of a chairman elected from the group—such chairman usually, but not always, being the representative of the largest single interest in the project. One of the usual requirements of the operating contract is that, if one operator owns or represents more than 50 per cent of the project, at least two votes are required for a quorum, said two votes to represent at least 60 per cent of the project.

The single and multiple committees may have provisions in the articles of organization for hiring outside technical assistance, or for the apportioning of the cost of community facilities among the member operators. Provision may be made for the specific selection of input wells and other communal matters.

The third type of cooperative is really no organization at all. It simply consists of either a letter of agreement, or it may take the form of a simple contract. Its contents and scope are usually brief, and may cover only such pertinent items as injection rates and volumes of fluids used; or it may go further and include provision for periodic surveys in regard to fluid levels, selection of input wells, or the drilling and distribution of costs for community wells, gas-oil ratios, oil and water production, and the back-pressuring of producing wells. It may also include agreement to transport water or gas, or both, from a source to the point of utilization. Other convenient and sometimes necessary exchange of needed data and facilities are provided for between the operators involved.

The fourth or last arrangement for cooperative effort may simply consist of a gentlemen's agreement. This understanding has worked, and does work, quite as efficiently in many cases as a more elaborate formal organization operating under written-rule limitations.

In those states that have regulatory bodies, any form of cooperative operation must have the approval of those agencies. In any event, the operators must conduct their operations in such manner that equities between leaseholds are maintained. Their operations should include a record of the facts that will enable the operators to prove, if necessary, before a court or regulatory body that reasonable equity has been maintained, and that efforts are being made to insure the continuance of such equity. Operators engaged in a cooperative project must be constantly alert to the dangers of false accusations.

● **Advantages over ordinary operation.** The advantages of cooperative secondary-recovery projects compared to the customary mode of operation between neighboring operators are many. The cooperative route is not, however, a panacea. Then, too, there exist all degrees of effectiveness throughout the gamut of the operational phase. Most of the operational success of a project is dependent entirely upon mutual trust between the operators concerned. On the other hand, we should never lose sight of the fact that natural reservoir conditions—all beyond the control of man—contribute to, and control to a great extent, the outcome of a project. Therefore, the factors relating to a project can be resolved into two principal categories, viz.: one controlled by man, and which can be labeled cooperativeness; the other, largely beyond the control of man, the natural physical conditions of any particular reservoir. Assuming that the operators involved in a given project have selected the correct fluid medium for injection and have made other plans for operation of the project correctly, maximum results can be forecast, with a reasonable degree of certainty.

The intelligence of the operators, together with full pooling of their experience in such matters, is invaluable. This, coupled with the ability to talk out controversial matters to a conclusion, without incurring any permanent ill will among them, goes a long way to dispel suspicions, should there be any, and thereby prevent the harboring of malignant fears.

Too much emphasis cannot be placed on the matter of utterly frank, thorough, and searching discussion and analysis of the problems at hand. Once decisions have been concluded, they can be executed at the opportune time.

It is obvious to all who have actively participated in such matters that the operation of secondary projects under the cooperative scheme leaves much to be desired, particularly that which concerns the limitations of the operators to close in, drill, and increase or decrease the rate of production from wells in the project. The fact that production must be maintained on all separate leaseholds, in order to perpetuate the leases, makes it mandatory on the part of operators.

Compared to sporadic, isolated, and usually smallscale individual secondary-recovery projects, the cooperative method has a major advantage. Also, it so happens that cooperative projects have paved the way to the formation of complete unitization, which includes all working and royalty interests that embrace all of a given common reservoir.

Cooperative projects have been, and are, a school for operators. Much educational value has been received by the operators, state regulatory bodies, and the industry as a result of these cooperative projects. Even though a particular project is a financial failure, much good is accomplished in the way of operator education. The operators, after experiencing a failure of this kind, are better fortified for their next encounter.

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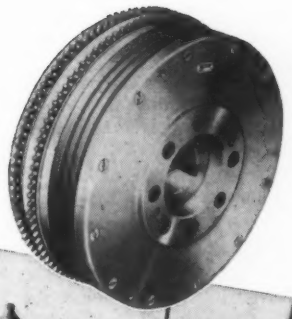
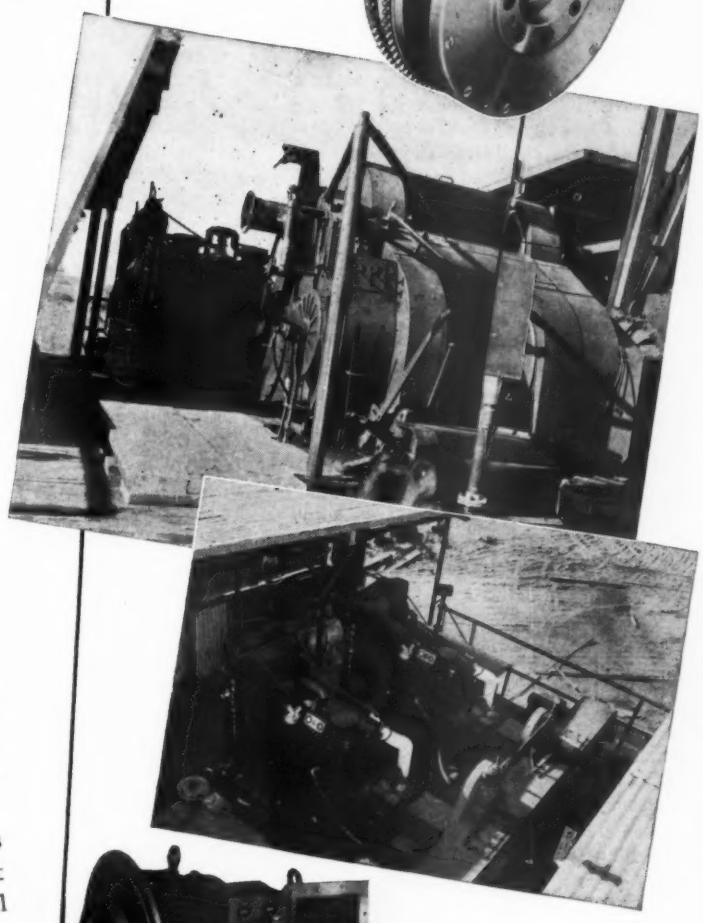
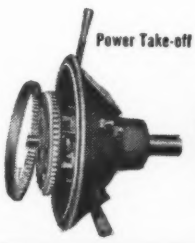


Model P Clutch

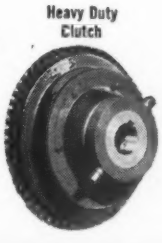


Hydraulic Torque Converter (Lysholm-Smith type).

This Emsco G-500 drilling rig, operating in southern California, has three Twin Disc Model P Air-actuated Clutches in the drawworks. Inset shows Hall-Scott power units on this rig, each equipped with a Twin Disc Hydraulic Torque Converter.



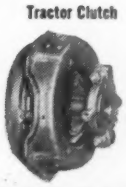
Power Take-off



Heavy Duty Clutch

Machine Tool Clutch

TWIN DISC
CLUTCHES AND HYDRAULIC DRIVES
REG. U. S. PAT. OFF.



Tractor Clutch

Marine Gear

SPECIALISTS IN INDUSTRIAL CLUTCHES SINCE 1918

Good records are more apt to be kept in the case of cooperative as compared to usual operation, no matter whether a particular project was a failure, a mediocre success, or an outstanding achievement. Thus technical data are available to more technicians and operators; therefore, sounder conclusions, in most cases, may be expected. This advantage is common to unitized projects as well as cooperatives. Individually owned and operated projects seldom attain the same degree of thought, consideration, and analysis.

Another advantage of unknown value, but no doubt of importance, to those taking part in the operations of cooperative projects is that the associations lead to a desirable personal understanding and acquaintanceship between the individuals, which contribute to the creation of either subsequent cooperatives or units in other fields and reservoirs.

Too much stress cannot be placed on the good that has accrued to individuals, operators, and companies alike from having participated in numerous meetings concerned with such matters. Committee meetings have been, and are, a forum where most problems can be satisfactorily solved if the principal or his representative enters into such discussions clothed with adequate authority and with an open and unbiased attitude. Management will do well to continue its wholehearted support of such matters.

The advantages of cooperatives, some of which are common to units, are:

1. Compilation of geological and engineering data for a given project approaches greater completeness.

2. There is a decided tendency and trend for the individuals participating in such meetings to grow in their ability to give and take on suggestions of others. This improvement is frequently conveyed to the mnaagement.

3. Thinking is stimulated. Oftentimes ingenious solutions are developed in committee meetings for what may appear to be insurmountable handicaps at the outset.

4. Permits the application of producing methods considered most applicable and, therefore, most efficient for the particular physical characteristics of the reservoir in question so as to recover ultimately the largest possible amount of crude oil. This is really the most important element.

Finally, the writer prefers to look on cooperative secondary-recovery projects as representing the first stage of advancement from individual operation. It is one step removed from individual-operator isolationism and one step nearer to complete unitization, which is the pinnacle of operational flexibility.

● **Disadvantages compared to unit operation.** The chief operational disadvantage of the cooperative type of secondary-recovery project, compared to unit operation, is obviously one of inflexibility. Other disadvantages are:

1. Most cooperative contracts permit any member-operator to withdraw. Such option can result in weakening greatly or destroying effectiveness of a project.

2. Certain reservoir conditions cannot be accommodated with respect to the highest degree of operating efficiency and, at the same time, maintain separate leasehold equity.

Heath[11] points out:

"Cooperative agreements between lease owners for simultaneous prosecution of secondary-recovery efforts have been in quite general use for a number of years. Such consist mainly of agreements concerning the placement of injection wells along lease boundary lines, with provisions governing the volumes to be injected thereto, and, in instances, providing for supply of the injection medium from a plant or system of one of the operators.

"Such mutually beneficial contracts, while commendable, contain only a minor semblance of the elements of cost savings that characterize a completely unitized effort. There is still considerable duplication of items of development and operating cost."

By its very nature, it is dependent upon cooperation between the several operators concerned. Consequently, it is highly important that all operators of a project be fortified with as much factual data, soundly analyzed, as possible. All needed facts and data, properly analyzed, increase the odds in favor of a common viewpoint as regards important decisions. Hence, there is less likelihood of controversy concerning important policy decisions.

Lesser points of objection to the cooperative type of organization, other than the disadvantages pointed out hereinbefore, are a tendency not to formulate a program that would require commounity facilities, and a tendency to deter employment of full-time technical aid for the project. The same may also be said with respect to community facilities. Operators in the Midway and Magnolia fields, Arkansas, have successfully installed community facilities for the injection of water for the purpose of primary pressure maintenance. The Hull-Silk-Sikes, the K-M-A, and the West Pampa Repressuring Association, all in Texas, have employed full-time technical personnel to supervise and make recommendations to the operators for carrying on secondary-recovery work. Provisions are made for project personnel in the articles of organization of these three projects. In the case of the West Pampa Repressuring Association, monthly assessments are made on the basis of monthly pipeline runs, each member-operator paying the same percentage of the total costs as the monthly production from his leases is of the total monthly production of the project. Such assessments provide the needed physical facilities for operating the project.

● **Conclusions.** 1. The formation and operation of the cooperative type of secondary-recovery project has greatly influenced, contributed to, and encouraged the development, formation, and perfection of units and unitization in general. Projects have been started as cooperatives, and later have been transformed into units.

2. It may be considered as a step in evolutionary improvement of the problem of greater ultimate recovery from common reservoirs owned by more than one operator.

3. Its usefulness certainly has not passed. In many cases its efficiency, under certain favorable conditions, approaches or equals that of complete unitization.

4. It is flexible with respect to avoidance of many legal and human obstacles.

5. The operators must, however, guard against operations that might cast any doubt on the matter of equity as regards individual leaseholds. In this respect, the cooperative method tends to be inflexible. However, equity can be achieved in most cases without excessive sacrifice of recovery or any undue economic penalty. Pooling of several individual leaseholds in a cooperative project, including both royalty and working interest—aided by property purchases—is important, and is often resorted to when all other possibilities are precluded.

6. State regulatory bodies have supported and encouraged the formation and operation of cooperative secondary projects.

7. Technological advances and improvement in human relationship between the operators and royalty owners serve to perpetuate the usefulness of the cooperative secondary-recovery type of organization for the purpose of reducing production costs, increasing the ultimate yield of crude oil, with attendant higher profits.

● **Acknowledgment.** The author wishes to express his sincere appreciation for the assistance given by John R. Coombs, petroleum engineer; Miss Elma Wood, librarian, Petroleum Engineering Department Library; Walace Hawkins and Raymond M. Myers, legal staff, Magnolia Petroleum Company. Also acknowledgment, with thanks, is made of information contributed by many individuals and the members of other company staffs.

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Appendix begins page 134

TYPE SES

Ball bearing unit pillow block—assembled and lubricated. Rubber-mounted for quiet operation.

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Self-aligning ball bearing unit pillow block—with ring seals to exclude dirt.

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APPENDIX

TABLE 1. Partial list of cooperative secondary-recovery projects.

(Active and inactive)

	Field, County, State	Injection medium
1.	Magnolia field, Columbia County, Arkansas	Water
2.	Midway field, Lafayette County, Arkansas	Water
3.	Smackover field, Union County, Arkansas	Gas
4.	Dominguez field, Los Angeles County, California	Gas
5.	Louden field, Fayette County, Illinois	Gas
6.	Rural Hill pool, Hamilton County, Illinois	Gas
7.	Siggins pool, Cumberland County, Illinois	Water
8.	Griffin field, Gibson and Posey Counties, Indiana	Gas
9.	Paint Creek Uplift field, Magoffin County, Kentucky	Air-gas
10.	Haynesville field, Claiborne Parish, Louisiana	Gas
11.	Homer field, Claiborne Parish, Louisiana	Gas
12.	Lisbon field, Lincoln and Claiborne Parishes, Louisiana	Gas
13.	Loco Hills field, Eddy County, New Mexico	Gas
14.	Maljamar pool, Lea County, New Mexico	Gas
15.	Bowlegs field, Seminole County, Oklahoma	Gas
16.	North Burbank field, Osage County, Oklahoma	Gas
17.	North Dill field, Okfuskee County, Oklahoma	Gas
18.	Red River field, Tillman County, Oklahoma	Gas
19.	Chapel Hill field, Smith County, Texas	Gas cycling
20.	Cook field, Shackelford County, Texas	Gas
21.	Eastland pool, Coleman County, Texas	Gas
22.	Fry field, Brown County, Texas	Gas
23.	Howard Glasscock field, Howard County, Texas	Water
24.	Hull-Silk-Sikes field, Archer County, Texas	Gas
25.	K-M-A field, Wichita and Archer Counties, Texas	Gas
26.	Loma Novia field, Duval County, Texas	Gas
27.	New Hope field, Franklin County, Texas	Water
28.	O'Hern field, Duval County, Texas	Gas
29.	Panhandle field, Gray and Carson Counties, Texas	Gas
30.	Stover pool, Brown County, Texas	Gas
31.	West Pampa field, Gray County, Texas	Gas
32.	Elk Fork field, Tyler County, West Virginia	Gas
33.	Fink field, Lewis County, West Virginia	Gas
34.	Rock Creek field, Roane County, West Virginia	Gas
35.	St. Marys field, Pleasants County, West Virginia	Air

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☆ ☆ ☆

TYPICAL MULTIPLE-COMMITTEE COOPERATIVE AGREEMENT

A. An Agreement Forming the West Pampa Repressuring Association
B. Articles of Organization, West Pampa Repressuring Association

The West Pampa Repressuring Association has been used as a specific example. There are three principal agreements in the association, two of which have been included. The service-agent agreement has been deleted due to length.

EXHIBIT "A"

An Agreement Forming the West Pampa Repressuring Association, West Pampa Area, Gray County, Texas

THIS AGREEMENT, made and entered into as of the ..... day of ....., 19....., by and between the parties signatory hereto,

WITNESSETH: That

WHEREAS, the undersigned parties are the owners of producing oil and gas leases in the West Pampa area, located in Gray County, Texas, which area is more fully shown within the red line on the plat attached hereto, marked Exhibit "A," and by reference made a part hereof; and the names of the respective owners of said oil and gas leases, and the number of wells thereon, are more fully shown on the schedule attached hereto, marked Exhibit "B," and by reference made a part hereof; and which said leases and area included therein, as outlined in Exhibit "A" attached hereto, shall hereinafter be known and referred to as the "West Pampa Repressure Area"; and

WHEREAS, it is the opinion of the parties hereto that, by cooperating with one another in a gas-repressuring project, there is a possibility that the recovery of crude oil from the Dolomite formation, which is the present producing formation in the "West Pampa Repressure Area," can be materially increased; and

WHEREAS, the parties hereto desire to form an unincorporated, non-profit association for such cooperative gas repressuring in an attempt to increase the recovery of crude oil from the said Dolomite formation in the "West Pampa Repressure Area," and desire to set forth herein the rights and obligations of the parties in connection with such repressuring to the end that there may be the greatest possible increase in the recovery of crude oil from said Dolomite formation, and that the correlative rights of the parties, and of their mineral and royalty owners, may be thoroughly and adequately protected,

NOW, THEREFORE, for and in consideration of the premises and the mutual covenants and agreements herein contained and to be kept and performed, and of the mutual benefits to be obtained by the parties as the result of cooperating with one another in gas repressuring in the "West Pampa Repressure Area," the parties hereto agree severally and among themselves as follows:

I Formation of Association

That an unincorporated, non-profit association, to be known as the West Pampa Repressuring Association, is hereby formed to support and maintain a repressuring project for the advancement of secondary methods of oil recovery from the Dolomite formation in the "West Pampa Repressure Area" in Gray

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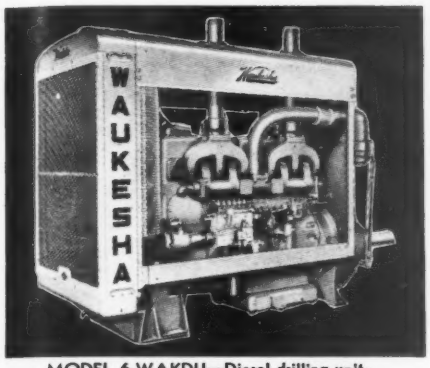
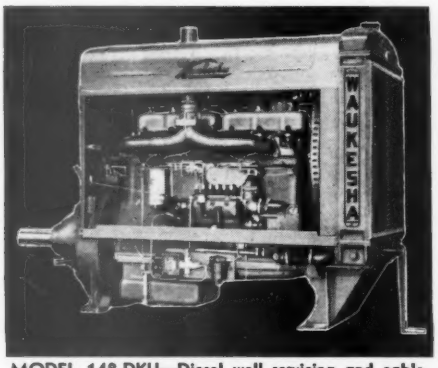
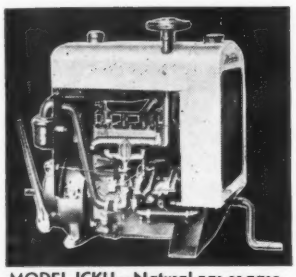


MODEL 6-WAKDU—Diesel drilling unit; 150-190 hp.

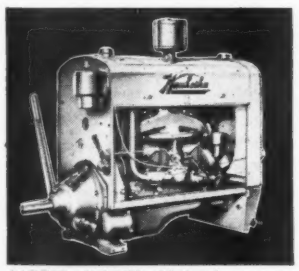


MODEL 148-DKU—Diesel well servicing and cable tool drilling unit; 78-147 hp.

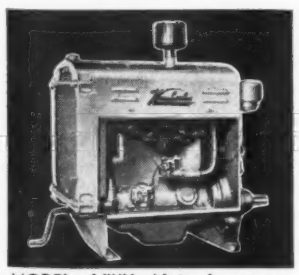
MODEL 190-DLBU—Diesel pumping and utility unit; 25-53 hp.



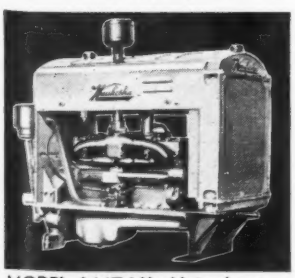
MODEL ICKU—Natural gas or gasoline unit; 8-16 hp.



MODEL XAHU—Natural gas or gasoline pumping and utility unit; 20-36 hp.



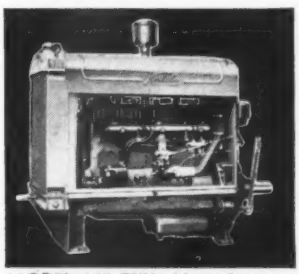
MODEL VIKU—Natural gas or gasoline pumping unit; 25-50 hp.



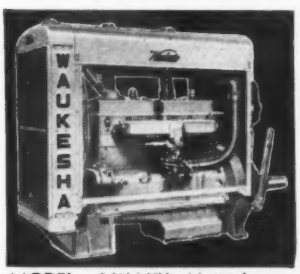
MODEL 6-MZAU—Natural gas or gasoline pumping unit; 50-75 hp.

OIL FIELD SERVICE AND PARTS DEPOTS

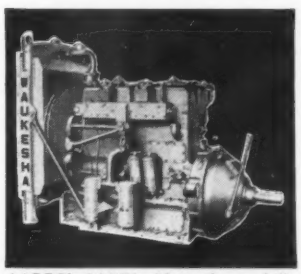
ARKANSAS	
J. B. Cook Auto Supply Company	Little Rock
CALIFORNIA	
Bethlehem Supply Company of California	Avenal Bakersfield Los Angeles Santa Fe Springs Taft Ventura
Waukesha Motor Company (Branch)	Los Angeles
CANADA	
Precision Machine & Fdry. Ltd.	Calgary, Alta.
COLORADO	
Power Service Company	Denver
ILLINOIS	
Oil Field Motor Service	Grayville
Oil Well Supply Company	Mt. Carmel
National Supply Company	Clay City
KANSAS	
T-V Supply Company	Great Bend
KENTUCKY	
Wombwell Automotive Parts Co.	Lexington
LOUISIANA	
Mechanical Equipment Co.	New Orleans
Waukesha Sales & Service, Inc.	New Iberia
MICHIGAN	
Oil Well Supply Company	Mt. Pleasant
MISSISSIPPI	
Reagan Tool Company	Hattiesburg Natchez
MONTANA	
Henes Bearing & Industrial Supply Co.	Billings
Power Service Co.	Denver, Colo.
OKLAHOMA	
Hopeman Equipment Company	Seminole
J. A. Werme Steel & Iron Works	Oklahoma City
Waukesha Motor Company (Branch)	Tulsa
PENNSYLVANIA	
Bradford Supply Company	Bradford
Oil Well Supply Company	Oil City
Motive Parts Co.	Pittsburgh
TEXAS	
Waukesha Sales & Service, Inc.	Corpus Christi Dallas Houston Kilgore Odessa Wichita Falls
WEST VIRGINIA	
Oil Well Supply Company	Charleston
WYOMING	
Power Service Company	Casper



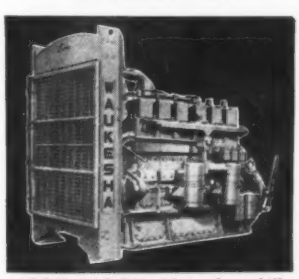
MODEL 145-GKU—Natural gas or gasoline servicing unit; 110-167 hp.



MODEL 6-WAKU—Natural gas servicing and drilling unit; 156-210 hp.



MODEL 6-NKU—Natural gas drilling unit; 150-225 hp.



MODEL 6-LROU—Natural gas drilling unit; 250-409 hp.

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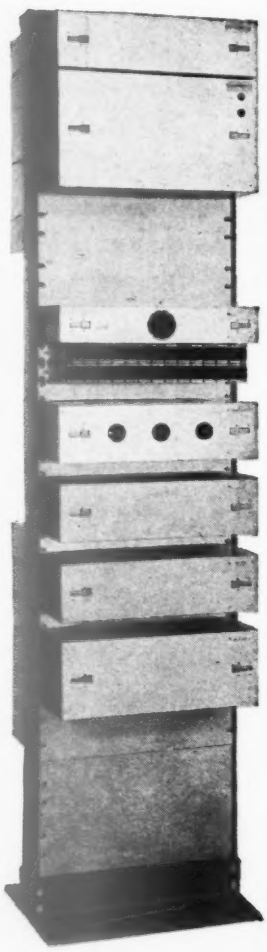

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County, Texas, and all activities of such association shall be conducted in accordance with the Articles of Organization attached hereto, marked Exhibit "C," and by reference made a part hereof for all purposes.

II Payment of Expenses of Association

Each party hereto agrees with the other parties executing this instrument and with those parties who may from time to time hereafter execute, ratify or adopt same, to contribute to the expenses of the association in accordance with the Articles of Organization hereto attached, and to be bound otherwise by said articles in all respects and to the same extent as if the articles were copied in this instrument in full.

III Obligations of Parties

Each party agrees that it will cooperate with the other parties hereto in the establishment and maintenance of a gas-repressuring project to inject gas into the Dolomite formation in the "West Pampa Repressure Area" in an effort to increase the ultimate recovery of oil from said Dolomite formation, and to accomplish said purpose each party hereto agrees with the other parties hereto as follows:

A. To execute with Skelly Oil Company and Cities Service Oil Company, simultaneously with the execution of this agreement, a repressuring service agreement on the form attached hereto and made a part hereof as Exhibit "D," setting forth, among other things, the cost of repressuring service and the method of reimbursing and guaranteeing payment for the investment to be made by said companies, herein referred to as "service agents."

B. To furnish and equip at its own expense for use as repressure input wells on its lease premises within said area and to use for such purpose such existing well or wells thereon as may be designated by the Executive Committee of the West Pampa Repressuring Association. In designating such input well or wells, the Executive Committee shall follow the desire of the owner thereof as far as is consistent, in the opinion of the Executive Committee, with the purpose and success of the repressuring project.

C. (1) To pool its available repressure residue gas (as defined in Exhibit "D") with the available repressure residue gas of the other parties hereto so that each party may have available for injection purposes sufficient residue gas to fulfill its gas-input obligations under this agreement. There shall be no charge for such gas, as such, to any party required to draw on the pooled gas to meet its injection obligations. Each operator shall be liable for the royalty, if any, on the residue gas it contributes to the pool.

(2) If and when a volume less than all available repressure residue gas of the operators is used for repressuring purposes during any accounting month, the balance thereof remaining unused for said purposes during said month shall be deemed to have been restored to its former status of unpooled gas and credited to the respective leases into which there was injected less than the volumes contributed by them respectively to the pool. The basis of crediting each such lease with its part of said balance shall be in the proportion that the excess of the contribution of said lease to the pool bears to the total of the excesses from all leases having an excess.

(3) In any case where an input well serves two or more leases, then, in the absence of an agreement between the operators of such leases, the pool engineer, under the direction of the Executive Committee, shall determine what proportionate part of the gas injected through such well during the accounting month shall be charged to each of said leases, and shall so notify the owners of all plants receiving casinghead gas from said leases.

D. To inject or permit service agents to inject into the Dolomite formation through its repressure input well, or wells, at all times the volume of gas designated by the Executive Committee of the West Pampa Repressuring Association to be returned to such repressure well or wells.

E. No party shall substitute, discontinue the use of or add repressure input wells, or vary the gas injection into its repressure input well, or wells, without the approval of the Executive Committee of the West Pampa Repressuring Association.

F. To keep such records of oil, water, and gas production, well perfomance, and other facts as may be of importance in determining the results of such gas injection as may be required by, and to make such information available to, the pool

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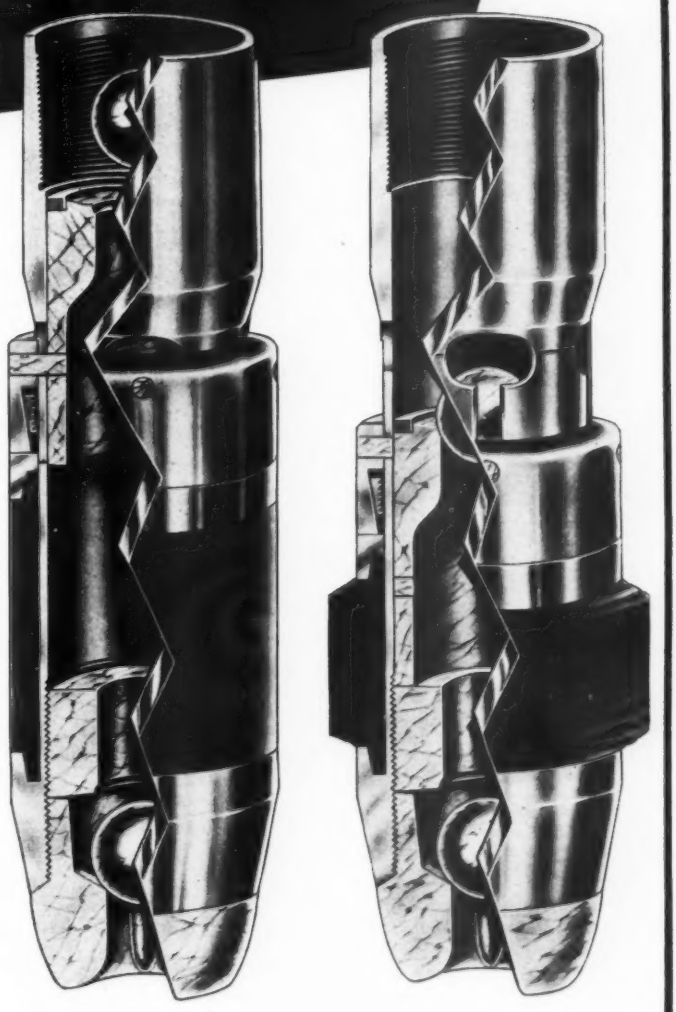

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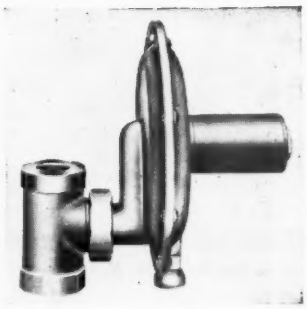

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engineer, Executive Committee, or the representative designated by the Executive Committee to determine such matters and to collect and receive such information and data.

G. To conduct its operations in the "West Pampa Repressure Area" in a manner consistent with the cooperative intent of this agreement, to the end that each party to this agreement may obtain its fair share of the maximum possible benefits to be obtained by this cooperative repressuring project.

H. Each of the parties hereto agrees to pay its proportionate part of the cost of repressure service each month. Such cost shall be apportioned among the respective members in the ratio that the total number of barrels of crude-oil pipe-line runs from the lease or leases of each such member in the repressured area during the preceding calendar month bears to the total barrels of crude oil run into the pipe line or lines from all the leases in said area of all the members during said preceding calendar month. The members, through their pool engineer or other agent upon whom such duty shall be imposed by the Executive Committee, shall on or before the 20th day of each calendar month furnish to the service agents a statement in writing setting forth said oil runs for the preceding calendar month or the proportionate part which each of the members is to pay of the total costs for the then current month; provided that the foregoing basis of allocation of cost of repressure service may be changed only on the written approval or agreement of members then owning not less than ninety per cent (90%) of the percentage interest in the oil runs in said area computed in the manner provided for in Par. 3 of Sect. IX of the Articles of Organization attached hereto as Exhibit "C."

IV No Partnership Liability

Joinder herein shall in no manner create any partnership or other relation between the parties hereto except that of separate corporations or individuals undertaking the separate obligations herein provided. Neither shall any party have any responsibility or liability to any other party for operations hereunder except as specifically set forth herein, nor shall any party have any responsibility to third parties for the liabilities of other parties hereto. However, the provisions of this paragraph are not intended to alter or affect the joint and several liabilities of the joint owners of any lease in said area.

V Effective Date of Agreement

This agreement shall not become effective unless all of the parties named in Exhibit "B" join herein and in the said agreement marked Exhibit "D" with said service agents, provided, however, that in the event less than all of the parties named in Exhibit "B" join herein and in the said agreement Exhibit "D," those who have joined, or any number thereof, may waive the requirement of complete joinder, and may elect to be bound by letter agreement to that effect, in which event the parties so electing shall be fully bound hereby and by the said service-agent agreement. Each party joining herein shall, however, be bound for a period of one hundred and twenty (120) days from the date hereof while efforts are being made to secure the signatures of other parties.

Actual repressuring operations shall be commenced as soon as possible after this agreement becomes fully effective, and each party shall be bound hereby for a period of eighteen (18) months from the date actual gas injection commences, and thereafter during the term of this agreement subject to the right of withdrawal in any party hereto as to its lease, or if it has more than one as to one or more thereof, after the expiration of said eighteen (18) months upon (1) such party making a proper showing to the Executive Committee that the operations hereunder are not profitable as to each lease sought to be withdrawn, and (2) such party paying in full all obligations assumed and incurred by it by reason of such lease or leases under the terms and provisions of this agreement up to the date of its withdrawal.

The Executive Committee shall act on the application for withdrawal of any member from the association within sixty (60) days after the receipt of such application, and, in the event of any disagreement between such member and the Executive Committee, such member shall have the right to have its application considered and passed on by the Operators' Committee. The Operators' Committee shall act upon such application within sixty (60) days after receipt thereof, and decision of the Operators' Committee in the case shall be final.

VI Term of Agreement

This agreement shall extend for a term of twenty-one (21) years and as long thereafter as repressuring operations are conducted in the "West Pampa Repressure Area," unless such agreement is sooner terminated by vote of the Operators' Committee as provided for in Sect. IX of the Articles of Organization hereto attached as Exhibit "C."

VII Transfer of Interests

Any sale, assignment, or other transfer of any interest of any party hereto in the lease or leases covered hereby shall be made expressly subject to this agreement and to the said agreement marked Exhibit "D" with said service agents, and shall not be binding on the Operators' Committee or the service agents, or any party hereto other than the party selling, assigning or transferring such interest unless and until a true and correct copy of the instrument evidencing such change in ownership has been delivered to the Operators' Committee and to each of the service agents. Such sale, assignment or other transfer shall expressly provide that the party or parties acquiring such interest shall assume and agree to bear its or their proportionate part of all cost and expense and other obligations chargeable under this agreement or the agreement with said service agents to, and imposed upon, the interest acquired or the party owning such interest, and said acquiring party or parties shall likewise receive its or their proportionate part of all benefits accruing under said agreements.

VIII State and Federal Laws and Regulations

This contract shall be subject to all laws and all rules and regulations prescribed by any duly constituted federal or state regulatory body having jurisdiction in the premises, including directives issued by federal agencies incident to the war and contracts by any party with the federal government or federal agencies to promote the war effort.

IX Force Majeure

In the event any party to this agreement is rendered unable in whole or in part by *force majeure* to carry out its obligations under this agreement, other than to make payments due hereunder, its obligations so far as they are affected by such *force majeure* shall be suspended during the continuance of any inability so caused, and reasonable efforts shall be made to remedy such cause with all reasonable dispatch.

The term "*force majeure*," as employed herein, shall mean acts of God, strikes, lockouts, or other industrial disturbances, acts of the public enemy, wars, blockades, riots, epidemics, lightning, earthquakes, arrests, explosions, priority regulation of any government having sovereignty, accident to machinery or pipe, altercations, failure of gas supply, and any other causes, whether or not of the character above enumerated, not within the control of the party claiming suspension and which by the exercise of due diligence such party is unable to overcome. It is understood that the settlement of strikes or lockouts shall be entirely within the discretion of the party having the difficulty, and the requirement that reasonable efforts shall be made to remedy the cause promptly shall not require the settlement of strikes or lockouts by acceding to the demands of the opposing person or organization when such course is inadvisable in the discretion of the party having the difficulty.

X Counterparts

This agreement may be executed in as many counterparts as deemed necessary and, when so executed, shall have the same effect as if all parties had executed the same instrument, or this agreement may be joined in or ratified by any necessary party or parties by separate instrument specifically referring hereto and identifying this agreement, and such shall have the same effect as if said party or parties had actually placed its or their signature hereon.

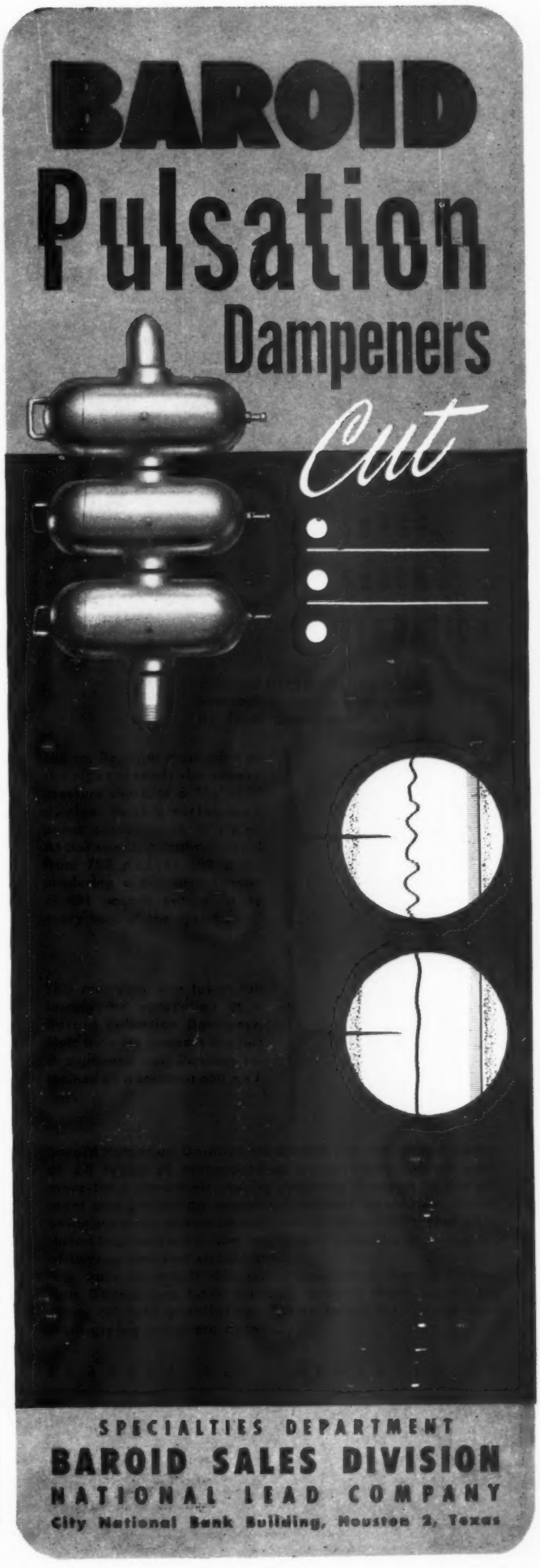
XI Operators Referred to by Pronoun "It"

Whenever in this agreement, or in the Articles of Organization attached herteto as Exhibit "C," operators are referred to by the pronoun "it," same shall include individuals in the case of those operators who are individuals.

XII Covenants Running with Land

The terms and provisions hereof shall extend to and be binding upon the parties hereto, their heirs, successors, and assigns; and shall constitute a covenant running with the lands and leasehold estates affected hereby.

IN WITNESS WHEREOF, the parties hereto have signed this



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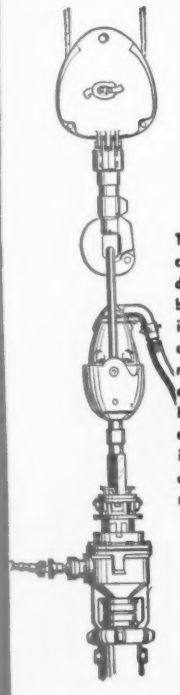

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agreement in quadruplicate originals, on the day and date hereinabove first written.

ATTEST:

.....
Secretary

.....CO.

By.....
President.

ATTEST:

.....
Secretary

ATTEST:

.....
Secretary

ATTEST:

.....
Secretary

EXHIBIT "B"

Articles of Organization, West Pampa Repressuring Association, West Pampa Area, Gray County, Texas

SECTION I—Name

The name of the association shall be the West Pampa Repressuring Association.

SECTION II—Objects and Purposes

The association shall be an unincorporated, non-profit association ,and its objects and purposes shall be to support and maintain a repressuring project for the advancement of secondary methods of oil recovery from the Dolomite formation in the West Pampa area, Gray County, Texas. It is not intended that the association shall furnish gas used for input purposes or perform any physical acts in connection with delivering gas, but shall serve only in an advisory capacity.

SECTION III—Membership

Any owner or operator of an oil well actively engaged in the development and production of oil from the Dolomite formation in the West Pamp area proposed to be covered hereby shall be eligible for membership in the association.

SECTION IV—Area

The West Pampa area proposed to be covered hereby, and designated as the "West Pampa Repressure Area," is shown within the red line on the plat attached as Exhibit "A" to the agreement forming said association.

SECTION V—Organization

1. There shall be an Operators' Committee, which shall be composed of one representative designated by each member of the association and immediately upon the agreement forming the association becoming effective in the manner provided for in Sect. V thereof, each member shall, by letter addressed to J. B. Steele, temporary chairman of Executive Committee, West Pampa Repressuring Association, P. O. Box 729, Tulsa (1), Okla., designate an authorized representative to represent such member on the said Operators' Committee.

2. There shall be an Executive Committee which shall be composed of seven members; four members of which committee shall be technically trained petroleum engineers, and all members of which Executive Committee shall be selected by the Operators' Committee.

3. The officers of the association shall be a chairman, a vice chairman, and a secretary-treasurer, each of whom shall be selected by the Operators' Committee from its own membership. The chairman, vice chairman, and secretary-treasurer shall serve in like capacities on the Executive Committee. All officers shall serve without remuneration. The duties of such officers shall be those customarily exercised, except as otherwise herein specified.

SECTION VI—Duties of Committees

1. Operators' Committee.

The Operators' Committee shall constitute the overall governing and policy-making body of the association, and such committee shall have the authority to delegate, from time to time, such powers and duties to the Executive Committee as it may deem necessary and advisable to carry out the objects and purposes of the association.

2. Executive Committee.

The Executive Committee shall be charged with the management and control of the operation of the repressuring project within the West Pampa Repressure Area in accordance with the powers and duties delegated to such committee from time to time by the Operators' Committee, and shall be charged

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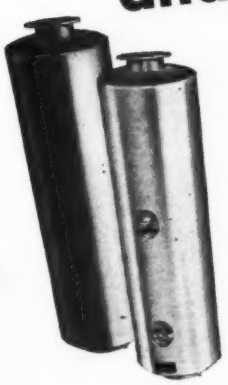

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Burgess Snubbers are designed on the exclusive snubbing principle, originated by Burgess-Manning. They provide adequate control of noise caused by irregular gas flow.

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with the responsibility of employing and supervising the work of a paid, full-time, competent pool engineer, thoroughly experienced in the production of oil and gas, and with providing such engineer with office space, office help, and other facilities deemed necessary from time to time by the Executive Committee.

The pool engineer shall carry on all necessary engineering work and such other duties as may be assigned to him by the Executive Committee.

The Executive Committee may, from time to time, appoint any subcommittee or subcommittees it considers necessary.

SECTION VII—Term

All officers and committeemen of the association shall serve for a term of one year from date of election or appointment and until their successor or successors are elected, as provided for in Subsection 2 of Sect. IX hereof.

SECTION VIII—Functions and Duties of Pool Engineer

The pool engineer shall be directly responsible to the Executive Committee and his primary duties, subject to the supervision of the Executive Committee, shall be:

1. To organize, supervise, and maintain a competent staff necessary to efficiently plan and carry on a gas-injection program.
2. To make a complete study of the reservoir by analyzing the history and characteristics of wells in the project and to keep familiar with changing reservoir conditions.
3. To recommend gas-input wells and volumes, initially and in the future, after proper consultation with individual operators.
4. To make recommendations to the Executive Committee and promote methods on ways and means of effecting good cooperation among the various operators, of increasing the ultimate recovery and rate of recovery, and reducing costs to the operators.
5. To furnish monthly to members of the association a confidential report on repressuring operations with data as to lease and project, oil and gas production, gas-oil ratio, gas-input volumes to wells, returnable gas, and other pertinent data.
6. To initiate and promote the practice among the individual operators of producing wells on a schedule to maintain as nearly as is practical a steady rate of gas production over a 24-hour period to the gasoline plants.
7. To perform such duties as may be imposed upon him by the provisions of the agreement forming said association and the agreement, Exhibit "D," with the repressure service agents.

SECTION IX—Meetings and Voting

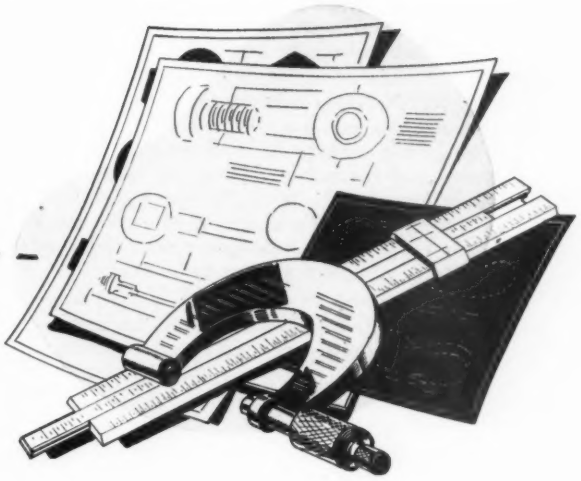
1. An initial or organization meeting of the Operators' Committee of the association to elect officers, select members of the Executive Committee, and transact such business as may come before the meeting shall be called by J. B. Steele, temporary chairman of Executive Committee, as soon as possible after the agreement forming such association becomes effective in the manner provided for in Sect. V of said agreement. Ten (10) days' written notice of the time and place of such meeting shall be given by the temporary chairman to all members.
2. The Operators' Committee shall thereafter hold an annual meeting on the third Tuesday of May of each year to elect officers, select members of the Executive Committee, and transact such business as may come before the meeting. Ten (10) days' written notice of the time and place of such meeting shall be given by the chairman to all members. Any other meeting of the Operators' Committee may be called by the chairman upon the written request of five or more members, at such time and place as the Executive Committee may select, after 10 days' written notice thereof to all members.
3. At each meeting of the Operators' Committee every member thereof shall be entitled to one vote by virtue of his membership on the committee, and a vote equal to the percentage of interest which the operator who designated him for membership on the committee had in the total oil runs in the area in the first three (3) calendar months of the last four (4) calendar months prior to the calendar month in which the meeting is held, in voting at an election of any officer or officers or on any motion or resolution. No person shall be elected as an officer, nor shall any motion or resolution be passed or adopted, unless both the votes of a majority of the members voting and the votes of a majority in percentage of interest in said oil runs be cast favorably thereto. Any member may so vote in person or by written proxy. It shall be the duty of the chairman to advise all members, in writing, at least 10 days in advance of any meeting, of any known questions affecting the affairs of the association which will be presented at such meetings so as to allow non-attending members to vote thereon. Non-attending members may vote on any such questions by mail or wire addressed to the chairman, provided same is received not later than the day before the scheduled meeting.
4. The foregoing provision for voting by non-attending members shall not preclude the decision of any additional questions affecting the affairs of the association, or decision of motions to amend the known questions of which the members had been previously notified, which may be brought up at such meetings, and as to such questions or motions a majority vote, in interest and numbers as above provided, of members in attendance in person shall prevail.
5. A meeting of the Executive Committee may be called by the chairman upon his own volition or upon the written request of two or more members thereof, after 10 days' notice in writing to all its members. At any meeting of the Executive Committee, five members shall constitute a quorum. Each member of the Executive Committee shall be entitled to one vote on any question affecting the affairs of such committee, and no motion or resolution shall be passed or adopted unless a majority of those voting cast their votes in favor thereof.

SECTION X—Financing and Administration

1. The pool engineer shall prepare a semi-annual budget which shall be submitted to the Executive Committee for its action. He shall also submit a monthly report of actual expenditures made for equipment to be purchased and to cover expenses of carrying out and properly handling his duties. This monthly report must be approved by at least one officer and one member of the Executive Committee.
2. An operating fund of not to exceed ten thousand dollars ($10,000) shall be raised out of which expenses shall be paid, especially initial expenses incurred by the association. This fund shall be raised by the members in the proportion which each member's pipe-line crude-oil runs during the three (3) calendar months prior to the date of the agreement to which these Articles of Organization are attached as Exhibit "C" bears to the total pipe-line crude-oil runs of all members for such three (3) calendar months from the area.
3. In order to defray the costs and expenses incurred by the association, each member shall pay to the association, monthly, its proper proportion of the total thereof, which shall be paid by the members in the proportion that the total number of barrels of crude-oil pipe-line runs from the lease or leases of each such member in the repressured area during the preceding calendar month bears to the total barrels of crude oil run into the pipe line or lines from all the leases in said area of all the members during said preceding calendar month; provided that the foregoing basis of allocation of the costs and expenses of the association may be changed only on the written approval or agreement of members then owning not less than ninety per cent (90%) of the percentage interest in the oil runs in said area computed in the manner provided for in Par. 3 of Sect. IX of these Articles of Organization.
4. All receipts of the association shall be deposited in a bank designated by the Executive Committee. Expenditures shall be made by check signed by the treasurer and pool engineer, and all expenditures except salaries shall be substantiated by properly signed receipts.
5. The pool engineer and the treasurer shall be bonded in an amount to be determined by the Executive Committee.
6. Each year the books of the association shall be audited by an auditing subcommittee of three to be composed of representatives of three different operators, who are members of the association, to be selected by the Executive Committee, or by a certified public accountant. The audit shall be complete and a written report made to the members of the association at least 10 days prior to the date set for such annual meeting.

SECTION XI—Enlargement of Project

Any owner or operator of an oil well actively engaged in the development and production of oil in the West Pampa Repressure Area or nearby areas may become a member of the association and have such wells become a part of the project and



LOOK FOR THE GREEN RODS

Specialized Experience

Because this organization concentrates its attention on the design, production, application of sucker rods, it is only natural for the industry to look to us for specialized knowledge of our products and their application. This specialization created the first all metal sucker rod. It has brought about a long string of other and equally important "firsts"... advancements and improvements that have helped make sucker rod pumping more efficient—more productive—and more economical.

● *Write for booklet on the "Care and Handling of Sucker Rods" as well as your copy of a folder describing the new Snap-Tite Wrench.*

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★ **THE S. M. JONES COMPANY**
(Subsidiary of Buffalo Bolt Company)
General Office and Factory: TOLEDO, OHIO
Sales Office: Kennedy Building, Tulsa, Okla.
Export Sales Office: Buffalo International Corp.
50 Church Street, N. Y. C.

subject to these Articles of Organization upon approval of the Operators' Committee. Upon such approval, such owner or operator shall be entitled to become a member of the Operators' Committee.

SECTION XII—Withdrawal

Each member of the association shall be bound hereby for a period of eighteen (18) months from the date actual gas injection commences and thereafter during the term of the operators' agreement forming the West Pampa Repressuring Association, subject to the right of withdrawal after the expiration of said eighteen (18) months, on such terms and conditions as are prescribed in Article V of said agreement.

SECTION XIII—Amendment of Articles of Organization

The foregoing Articles of Organization shall be amended only by a two-thirds vote (both per-capita and percentage) of the members in attendance in person and non-attending members voting by mail or wire, at any meeting of the Operators' Committee, provided that notice in writing of any proposed amendment must be first given to all members ten (10) days in advance of any such meeting.

☆ ☆ ☆

Typical Single-Committee Co-operative Agreement

Excerpt from a repressuring agreement. This section pertains specifically to the organization and functions of the committee.

Excerpt from Single-Committee Repressuring Agreement

Second: The **Operators** hereby establish an Operating Committee, the (A) composition, (B) duties, and (C) jurisdiction of which shall be as follows:

(A) The Operating Committee shall be composed of one representative of each **Operator** joining herein, to be designated in writing by such **Operator.** Each producing oil well and each key well, in the repressure area, shall be considered as one unit, and each representative on the Operating Committee shall have a vote equal in weight to the number of units represented by him at the time the vote is taken. Representation of fifty-one per cent (51%) of such units at a meeting shall constitute a quorum. A majority vote of the units represented at a regular meeting, or regularly called special meeting, of the Operating Committee at which a quorum is present, shall control and shall be binding on each **Operator,** and wherever in this agreement reference is made to a majority vote such type of majority vote is intended.

(B) The Operating Committee shall elect a chairman and secretary whose duties shall be those usually pertaining to such office. It shall fix the interval, time and place of its regular meetings. A special meeting may be called by the chairman or by any two (2) members by mailing notice thereof to the members at least ten (10) days before the date of such meeting. It shall be the duty of the Operating Committee to keep itself thoroughly familiar with the operations and progress of the repressuring project and to exercise the control thereof in this agreement provided.

(C) The Operating Committee shall exercise a general supervisory control over the repressuring project. In addition to such general supervisory powers, it is specifically provided:

(1) The Operating Committee shall have the specific powers granted to it by other provisions of this agreement.

(2) The Operating Committee, by a majority vote thereof, shall, from time to time, determine the pressure at which the repressure gas shall be injected into the injection wells of **Operators** up to and including the maximum pressure available at the wells under a pressure of five hundred (500) pounds per square inch at the intake of the ..... residue-gas system.

(3) The Operating Committee, by a majority vote thereof, shall, from time to time, determine the total volume of residue gas to be used in the repressuring project, considering the limits of the capacity of ..... compression equipment and return residue system.

(4) The Operating Committee, by a majority vote thereof, shall have the power to admit or deny admission to the repressuring project to other parties operating in the ..... pool, and to other leases, if any, of **Operators** that are not by this agreement included in the repressure area, and shall prescribe the terms and conditions under which any such party or lease may be admitted to the repressuring project.

(5) Termination of this agreement as between the **Operators,** and as between **Operators** and ....., shall be by a majority vote of the Operating Committee as constituted at the time of such vote, but this shall not prejudice the right of any **Operator** to withdraw herefrom after one (1) year as hereinafter provided.

☆ ☆ ☆

Typical Letter of Agreement

RE: Excess gas from .....lease, ...
Field, ... County, ...
Mr.....

.....

Dear Sir:

You are hereby granted permission to take gas from the .....wells on our.....lease in ..... County, ..., for the purpose of repressuring your lease, under the following terms and conditions:

1. It is agreed that you shall lay all lines necessary to connect with the casingheads of our.....wells on the above-mentioned lease at your entire cost, expense, and risk. It is understood that you will be responsible for any injuries sustained by your employees working on this gas system while on our lease, and that you will be responsible for any damages caused by said employees.

2. The gas which you shall take under this agreement shall be any amount you desire in excess of the amount needed by us in the normal operation of said lease.

3. All of the gas taken by you under this agreement shall be injected into a well or wells which directly offset our..... lease wells and which wells are completed in the same reservoir as the wells on our above-mentioned lease. The said gas may also be injected into any other wells where written approval to do so has been obtained from the ..... of .....Company in said district. The written permission of said..... must also be obtained before you may change the input wells being supplied with gas from our said .....lease wells.

4. The casinghead pressure on the wells on our..... .....lease shall not be reduced by you below atmospheric pressure (14.7 pounds, absolute) in the process of picking up said gas.

5. This agreement shall automatically terminate on ....., 19....., or may be terminated by either party prior to said date upon the giving of thirty (30) days' written notice to the other party.

6. On or before the.....day of each month you shall furnish to the said..... .....a report in triplicate showing the following data covering the previous month:

(1) The total volume of gas supplied to you by the wells from our..... lease;

(2) The volume of gas injected into each of the input wells selected under this agreement;

(3) The injection pressure used in injecting said gas into each of said input wells.

If the terms of this contract correspond to your understanding of this agreement, please sign a copy of this letter and return the same to us within five days, and this shall not constitute a contract between us until you have done so.

Yours very truly,

.....COMPANY

By.....

ACCEPTED this.....
day of....., A. D., 19.....

.....

● **General References.**

K. E. Beall, "Unitization in Oil Fields in the United States" (API Mid-Continent District meeting, Amarillo, May 1947) 26 p. (mimeographed).

F. R. Cozzens, "Cooperation Cuts Cost of Secondary Recovery," *Oil Weekly 107* [11] 47, Nov. 16 (1942).

H. W. Harts, "Industry Must Adopt Cooperative Gas-Injection Programs," *Oil Weekly 110* [2] 18, 20, June 14 (1943).

Interstate Oil Compact Commission, "Report of Legal Committee Relating to Secondary Recovery and Related Operations," *Interstate Oil Compact Quarterly Bulletin 1* [2] 62-3, July (1942).

Don R. Knowlton, "Proper Control of Oil Reservoirs," *Oil and Gas Journal 45* [34] 273-4, 278-9, Dec. 28 (1946).

James O. Lewis, "Advantages of Unitization in Repressuring" [API Mid-Continent District annual meeting, Oklahoma City, Feb. 15 (1934) *Oil and Gas Journal* (title: "Analysis of Some Advantages of Consolidating Old Oil Properties for Joint Repressuring") *32* [39] 45, Feb. 15 (1934).

Leslie Moses, "Some Aspects of Unit Operation of Oil Fields," *World Petroleum 14* [10] 42-4, Sept. (1943).

H. P. Pressler, Jr., "Legal Problems Involved in Cycling Gas in Gas Fields," *Petroleum Engineer 17* [11] 151-2, 154, 155, July (1946). ★ ★ ★

What is Dependability?

CUMMINS DIESEL

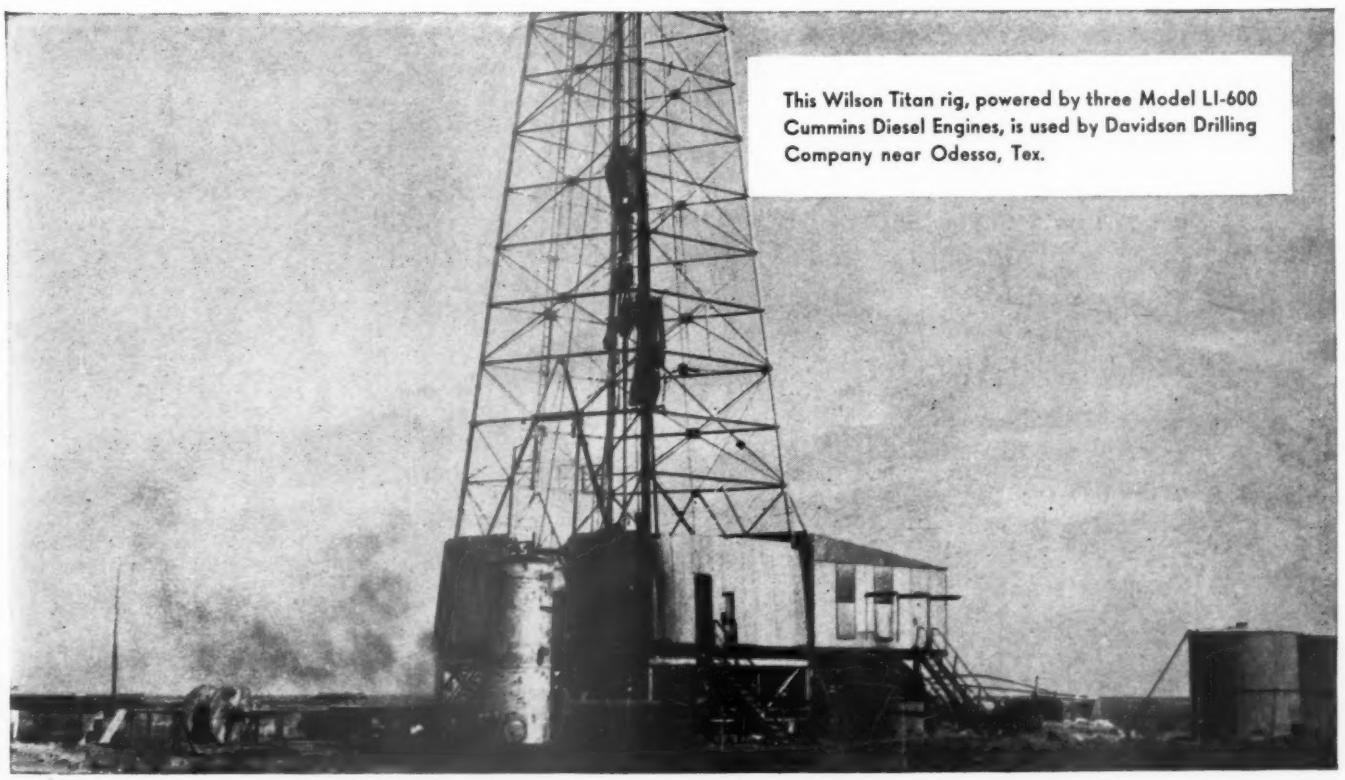
SINCE 1918...PIONEER OF PROFITABLE POWER THROUGH HIGH SPEED DIESELS

When you get right down to it: what is a dependable diesel?

It's an engine that gives reliable, day-after-day operation with minimum maintenance . . . the kind of operation Davidson Drilling Company gets from a Wilson Titan rig powered with three Model LI-600 Cummins Diesels.

In one deep-hole drilling operation near Odessa, Tex., the company's Cummins-powered rig worked 24 hours a day, seven days a week, and stopped only for oil changes. During the first year of operation no overhaul or major work was done on the engines. This rig drilled down to 8,750 feet in 61 days.

CUMMINS ENGINE COMPANY, INC.
COLUMBUS, INDIANA



This Wilson Titan rig, powered by three Model LI-600 Cummins Diesel Engines, is used by Davidson Drilling Company near Odessa, Tex.

Chemicals from petroleum*

By J. E. BLUDWORTH†

It is quite well known that acetaldehyde, acetone, methanol, and formaldehyde can be obtained directly from natural gas. By other and as well known methods the higher alcohols, aldehydes, and ketones can also be obtained from natural gas or some of its lower molecular weight components. If an attempt should be made to present, in any real degree, the total number of possibilities of chemicals from gas or its components the magnitude of the endeavor would be tremendous. If this effort should be further complicated by elaboration on or differentiation between methods for the manufacture of these chemicals, it is our belief the final result would be more confusing than informative.

We have taken, therefore, as the basis for our discussion some of the existing possibilities in the production of secondary products from a few of the better known primary or direct products of natural gas processing. Too little space and effort have been directed toward consideration of the tremendous possibilities of aldehyde, ketone, and alcohol uses. Too much has been invested in radical plant changes that can only reduce the cost of these primary compounds by a fraction of one cent.

In order to develop some degree of clarity as to the possibilities of acetaldehyde processing, we have attached to this discussion a flow sheet showing a number of the possible derivatives from this processing.

Acetaldehyde is reacted in the operation labeled 3A to give aldol, which can be reacted in second operations labeled 1B, 2B, etc.,to give other classes of compounds. The flow is continued until a series of four operations are shown here. In addition to the operations listed, product purification must be considered.

3A. Aldoling of aldehydes:

$$R{-}CH_2{-}CH{=}O \xrightarrow{NaOH} R{-}CH_2{-}\underset{\displaystyle OH}{\underset{|}{CH}}{-}\underset{\displaystyle R}{\underset{|}{CH}}{-}CH{=}O$$

Starting material	Aldol obtained	B. P.
Acetaldehyde	Acetaldol	83° 20 mm

$$CH_3{-}\underset{\displaystyle OH}{\underset{|}{CH}}{-}CH_2{-}CH{=}O$$

Starting material	Aldol obtained	B. P.
Butyraldehyde	Butyraldol	high

$$CH_3{-}CH_2{-}CH_2{-}\underset{\displaystyle OH}{\underset{|}{CH}}{-}\underset{\displaystyle CH_2{-}CH_3}{\underset{|}{CH}}{-}CHO$$

This reaction will go for any aldehyde having an alpha hydrogen.

The aldols are very useful chemical intermediates. They can be used as a source of glycols, conjugated unsaturated aldehydes, and ketones and beta hydroxy acids.

The aldols are formed in good yields. The aldols of aldehydes are sometimes difficult to separate from their corresponding aldehyde due to a cyclic acetal formation.

The formation of acetaldol from acetaldehyde is carried out in a slightly alkaline medium below room temperature. The medium is the reaction product, which is circulated through a reaction tank and a refrigeration exchanger to remove the heat of reaction. Acetaldehyde and small amounts of water and caustic are added to the recycle and reaction product withdrawn at the corresponding rate and acidified to stop the reaction.

The reaction rate is controlled by the temperature and alkalinity and is such that the reaction time is long enough that the reaction can be controlled. If the reaction is allowed to proceed too far, higher aldols than acetaldol are formed. Only about 60 per cent of the acetaldehyde reacts to form acetaldol, the remainder form a hemiacetal with acetaldol. The acetaldehyde in the hemiacetal cannot be removed from the reaction product by ordinary distillation, for the acetaldol dehydrates to crotonaldehyde under the influence of heat. By subjecting the mixture to vacuum at room temperature for an extended period of time the acetaldehyde can be stripped out, absorbed in water and recovered from the aqueous solution by distillation.

Acetals are formed from alcohols and aldehyes by heating in the presence of mineral acids and separating the acetal by fractionation after neutralizing the acid.

2A. $R{-}CH{=}O + 2ROH \xrightarrow{acid}$

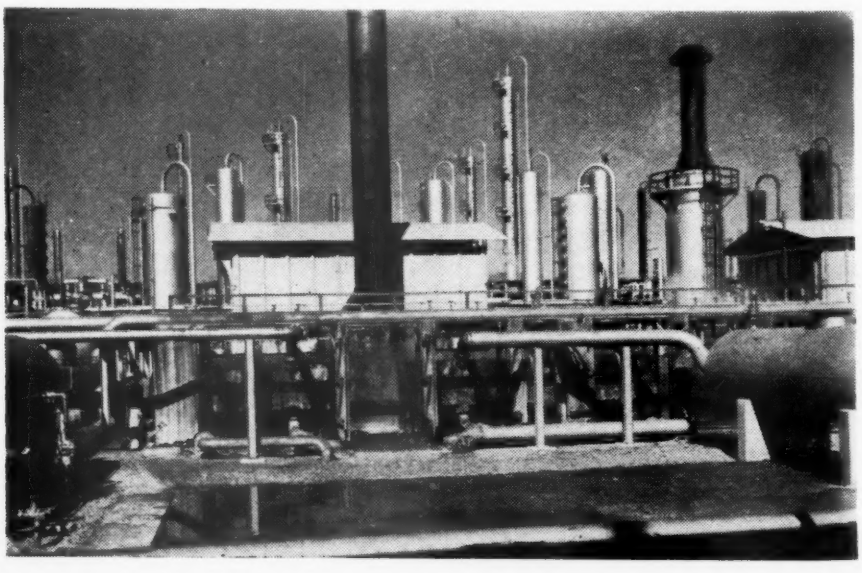
$$R{-}O{-}\underset{\displaystyle R}{\underset{|}{CH}}{-}O{-}R + H_2O$$

$$R{-}CH{=}O + R\underset{\displaystyle OH}{\underset{|}{CH}}{-}\underset{\displaystyle R}{\underset{|}{CH}}{-}\underset{\displaystyle OH}{\underset{|}{CH_2}} \longrightarrow$$

$$R{-}\underset{\displaystyle O}{\underset{|}{CH}}{-}\underset{\displaystyle O-C-O}{\underset{|}{\overset{\displaystyle R}{\overset{|}{CH}}}}{-}CH_2 + H_2O$$

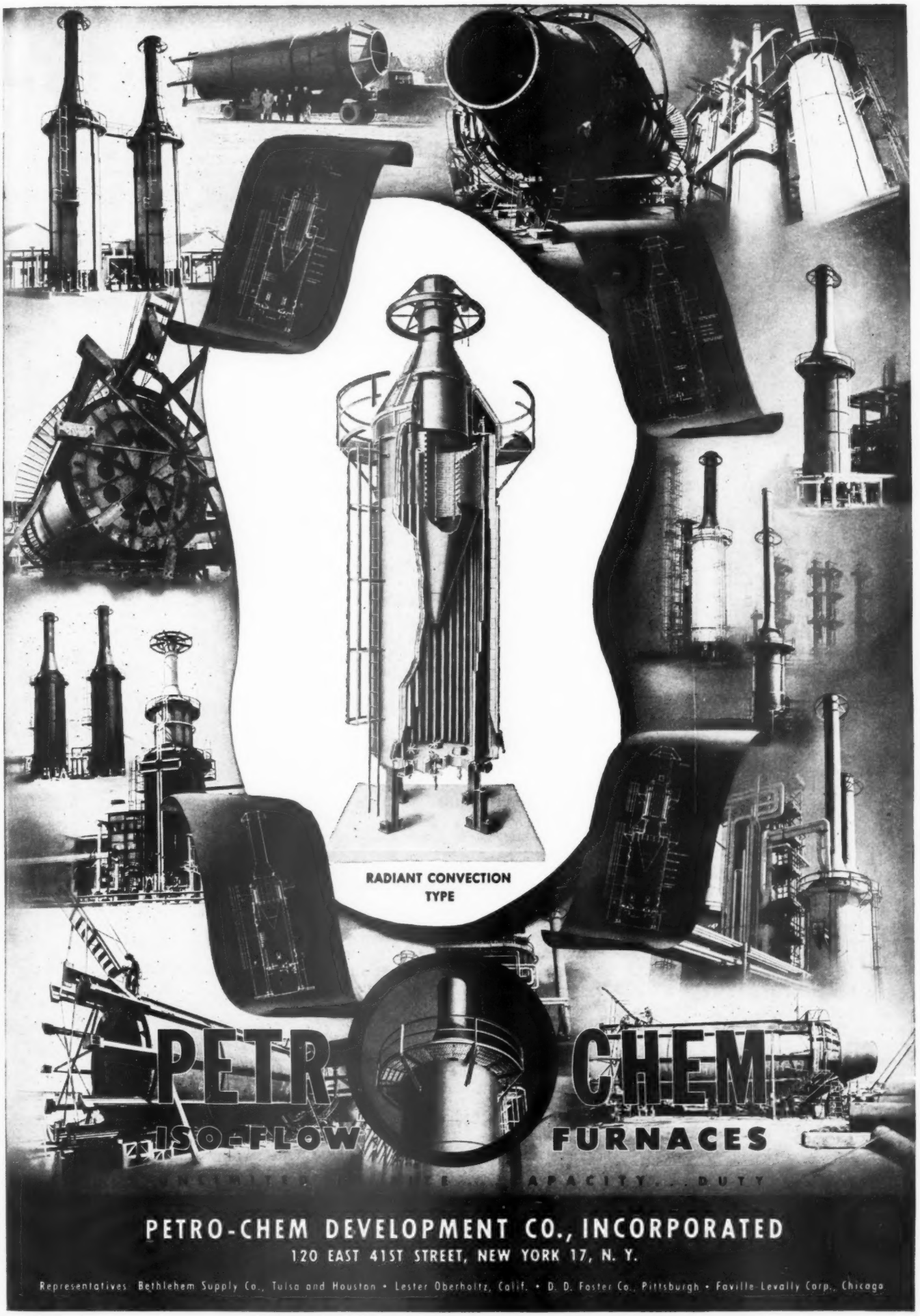
$$\begin{matrix} & & & & R & & \\ & & & & | & & \\ R & - & CH & - & CH & - & CH_2 \\ & & | & & | & & | \\ & & O & - & C & - & O \\ & & & & | & & \\ & & & & R & & \end{matrix}$$

Celanese plant, Chemcel, near Bishop, Texas.



*Presented before American Institute of Chemical Engineers, December 7, 1946, Port Arthur, Texas, and revised June 1, 1948.

†Formerly Director, Petroleum Chemicals Research and Development, Celanese Corporation of America. Since January, 1947, he has maintained offices at 832 Wilson Building, Houston, Texas, as petroleum and chemical consultant.


RADIANT CONVECTION TYPE
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PETRO-CHEM DEVELOPMENT CO., INCORPORATED
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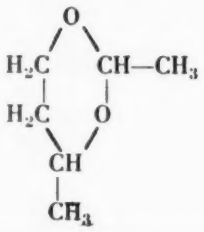
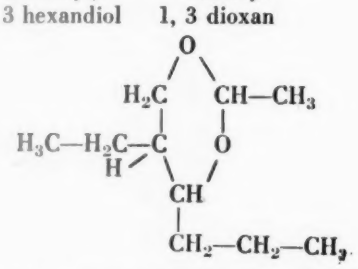
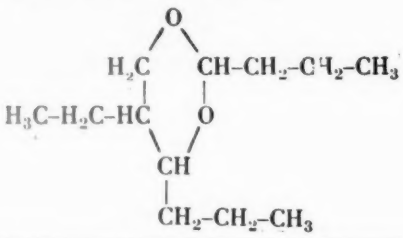
Representatives: Bethlehem Supply Co., Tulsa and Houston • Lester Oberholtz, Calif. • D. D. Foster Co., Pittsburgh • Faville-Levally Corp., Chicago

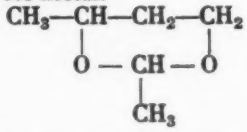
Starting material	Product	B. P. °C.
Acetaldehyde and ethanol	Diethyl acetal $H_3C-CH<(OC_2H_5)_2$	103
Acetaldehyde 1, 3 butylene and glycol	2, 4 dimethey, 1, 3 dioxan. 	150 est.
Acetaldehyde and 2 ethyl, 1, 3 hexandiol	4, 5 diethyl, 2 methyl 1, 3 dioxan 	220 est.
Butyraldehyde and butanol	Dibutyl butryal $H_3C-CH_2-CH<(OC_4H_9)_2$	200
Butyraldehyde and 2 ethyl, 1, 3 hexandiol	2, 5 diethyl, 4 butyl 1, 3 dioxan 	240 est.

Diethyl acetal is formed by the reaction of acetaldehyde with ethyl alcohol in the presence of a trace of acid. The unreacted acetaldehyde and alcohol, after neutralizing the acid, are recovered by fractionation and recycled.

The acetals are liquids with ether-like properties, fairly stable to alkaline hydrolysis but unstable to acids. They can be used generally as solvents. The cyclic acetals, dioxolane, and dioxanes, have been used to prepare resins. The cyclic acetals are fairly stable and have solvent properties similar to dioxane.

The acetals are prepared easily and in good yields.

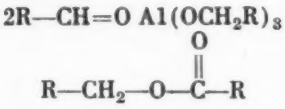
In a number of instances, products made from the starting materials in one or more operations could be reacted with the original reactants in a new series of operations. For instance, 1, 3 butylene glycol, made through operations 3A and 2B, could be condensed with acetaldehyde by operation 2A to give 1, 3 butylene glycol acetal.

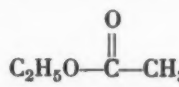
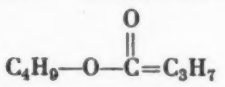
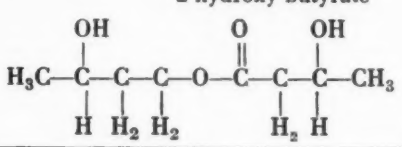


In such instances the number of operations required would be determined by studying the flow sheet.

The list of products is by no means complete, but it serves to illustrate the nature of the products obtained. Many other similar compounds not listed can also be prepared, if desired.

6A. Tischtschenko condensation of aldehydes to esters



Aldehyde used	Product	B. P.
Acetaldehyde	Ethyl acetate 	77
Butyraldehyde	Butyl butyrate 	166
Acetaldol	3 hydroxy butyl 2 hydroxy butyrate 	

This reaction is a general one for aldehydes but has not been commonly applied to manufacturing processes probably because of the difficulty in preparing catalysts.

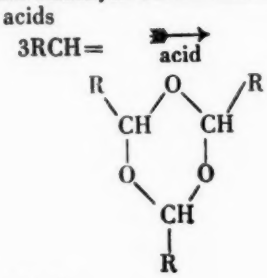
The reaction of two molecules of acetaldehyde to form ethyl acetate takes place in the liquid phase below room temperature in the presence of aluminum ethylate. Aluminum ethylate solution in ethyl acetate is prepared batchwise in a steel vessel equipped with a stirrer, reflux condenser and heating coils. A mixture of aluminum borings, aluminum chloride and ethyl acetate is heated to the boiling point, at which point the addition of absolute ethyl alcohol is started. Addition of the alcohol is continued over a period of 8-10 hr and reflux continued for 24 hr. The aluminum reacts completely to aluminum ethylate.

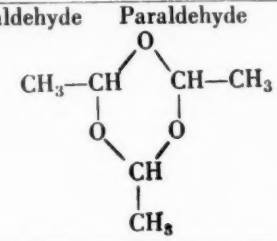
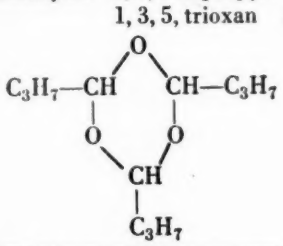
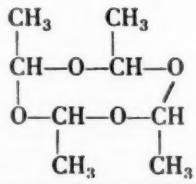
Equal weights of catalyst solution and anhydrous acetaldehyde are charged continuously to a brine-cooled reactor. The overflow from the first reactor goes to a second reactor maintained at a slightly higher temperature to complete the reaction. As the catalyst is not recoverable, the reaction product is treated in an evaporator with enough water to hydrolyze it to aluminum hydroxide and ethanol. The evaporator separates the liquids from the aluminum hydroxide.

The purification system consists of four columns, the first of which fractionates off the unreacted acetaldehyde. The second column fractionates off the ternary ethanol-ethyl acetate-water azeotrope, which is sent back to the evaporator where the water reacts with the unused catalyst. In the third column the overhead product is the binary azeotrope, ethanol-ethyl acetate, which is used for catalyst preparation. Finished ethyl acetate is the overhead product of the last column.

Mixtures of mixed esters can also be prepared by using a mixture of aldehydes as the reacting materials. For example, by condensing acetaldehyde and butyraldehyde together a mixture of esters would be formed containing ethyl acetate, butyl acetate, ethyl butyrate, and butyl butyrate.

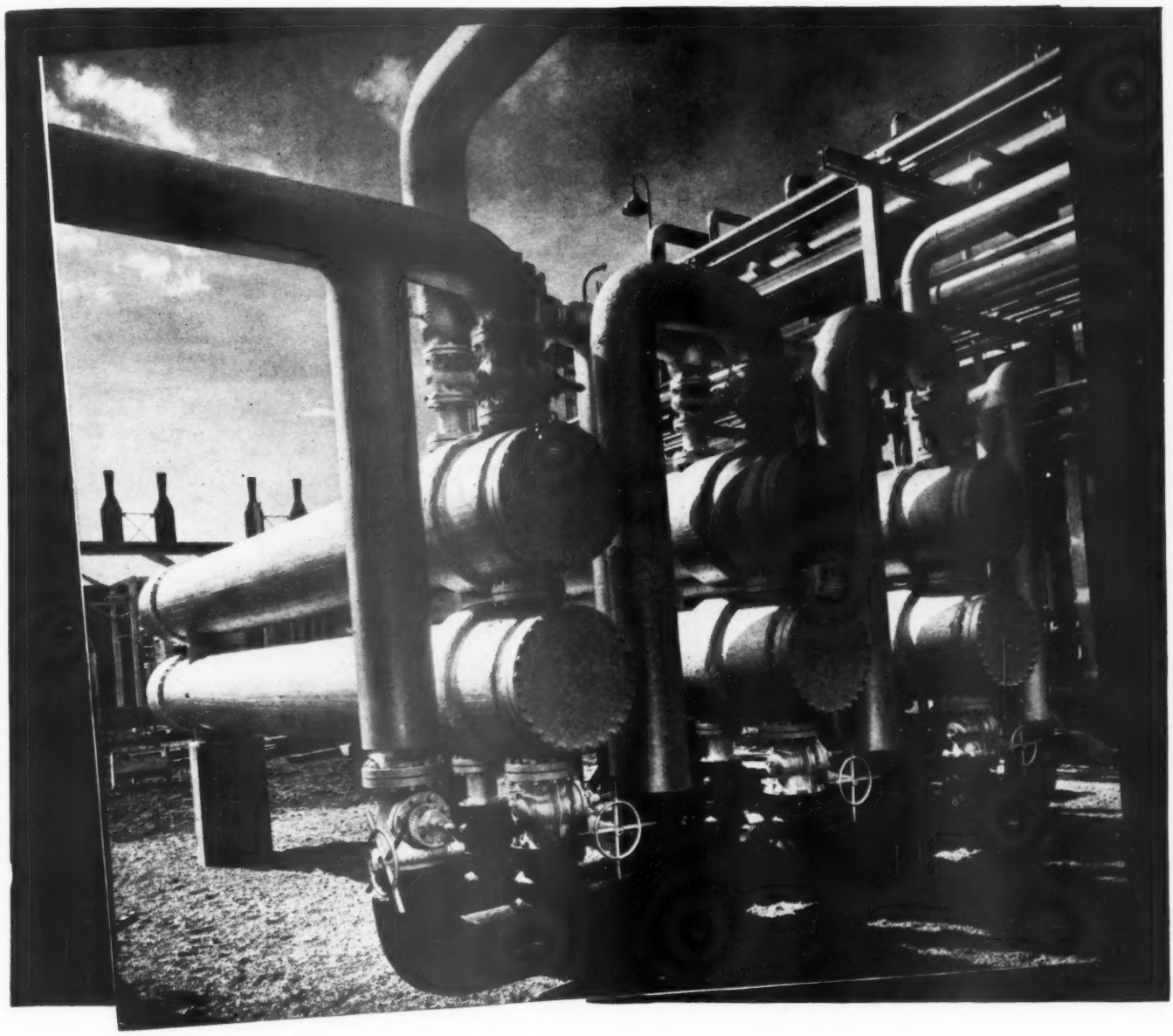
8A. Aldehyde condensations catalyzed by acids



Aldehyde condensed	Product	B. P.
Acetaldehyde	Paraldehyde 	124°
Butyraldehyde	2, 4, 6 tripropyl 1, 3, 5, trioxan 	100° 35 mm
Acetaldehyde	Metaldehyde 	Dec. 100°

In acid media the simpler aldehydes are known to go to their corresponding trimers in good yields. Acetaldehyde will also form a tetramer at low temperatures.

The compounds are unstable to acid or alkali and regenerate the aldehyde. For this reason they are often a good source of the anhydrous aldehyde and are easier to handle because of their



Good connections at Shell Oil

HERE is a picture of interest to everyone concerned with oil or chemical piping. The scene—a bank of heat exchangers at a Shell Oil Company cycling plant.

This labyrinth of critical piping was put together with Tube-Turn seamless welding fittings—the fittings that form a continuous, leakproof metal structure with the pipe. They are strong as the pipe itself. They fill the bill for truly permanent piping systems, free of maintenance problems.

Tube-Turn welding fittings are manufactured in a wide range of types, sizes, metals and alloys. Your nearby Tube Turns distributor carries a large stock. For fast service in good connections, specify "Tube-Turn."

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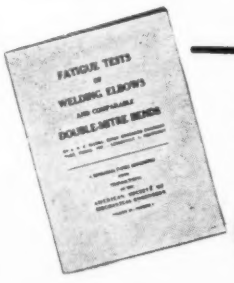
242 E. Broadway, Louisville 1, Ky.
District Offices at New York, Philadelphia, Pittsburgh, Detroit, Chicago, Houston, Tulsa, San Francisco, Los Angeles

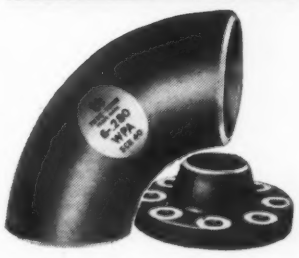


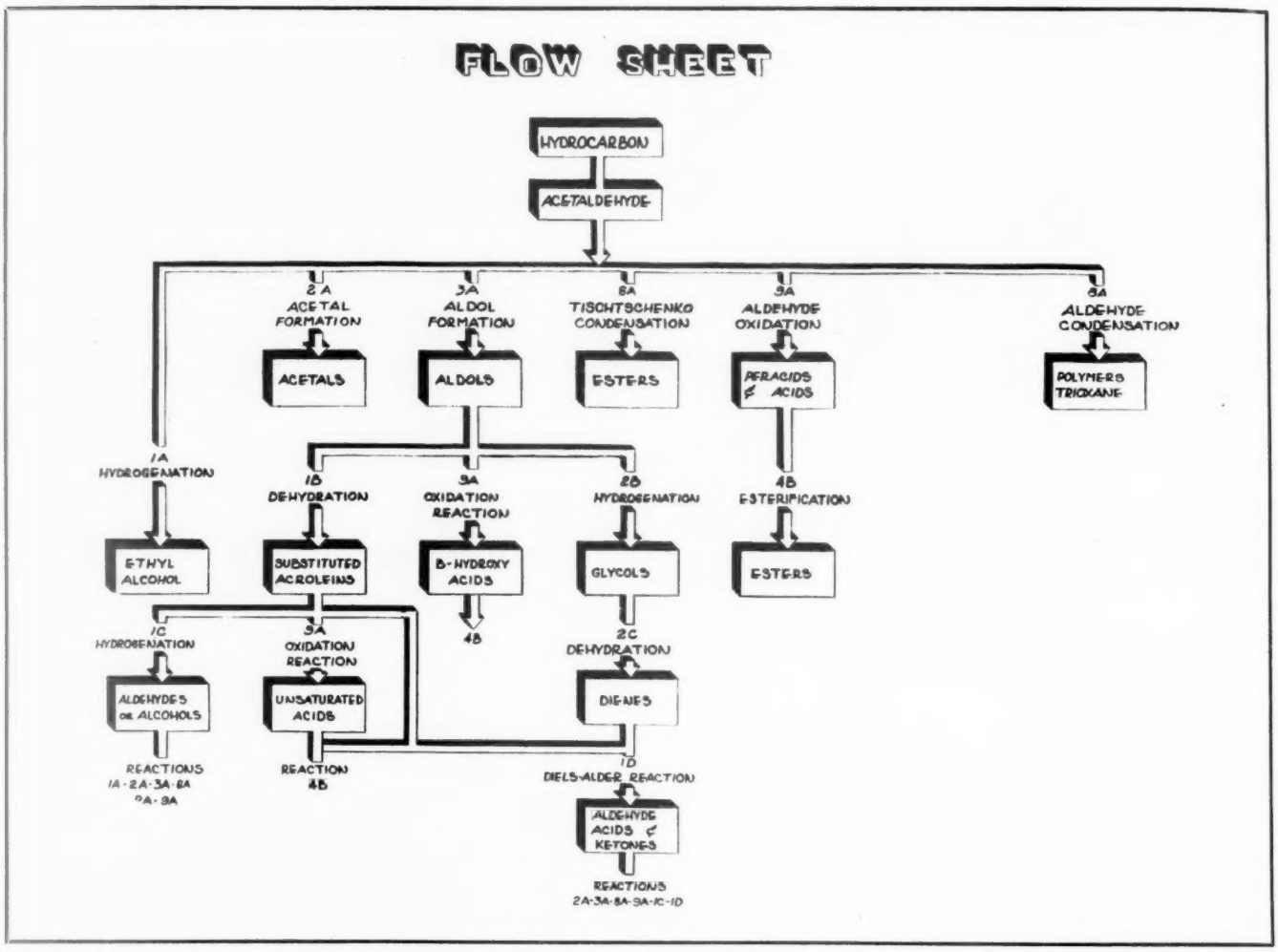
Write for copy of research paper presented before A.S.M.E., "Fatigue Tests of Welding Elbows and Comparable Double-Mitre Bends."

TUBE-TURN

tt

WELDING FITTINGS AND FLANGES





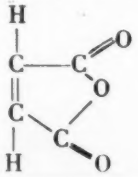
lower volatility and stability. Triexane is particularly useful as an anhydrous source of formaldehyde, because pure formaldehyde cannot be handled as a stable liquid.

Acetaldehyde is converted to paraldehyde by a trace of acid. The unreacted acetaldehyde can be fractionated off after neutralizing the acid.

9A. Oxidation of aldehydes

$$R{-}CH{=}O + O_2 \longrightarrow R{-}\overset{\overset{O}{\|}}{C}{-}O{-}OH \quad \text{(no catalyst)}$$

$$R{-}CH{=}O + \tfrac{1}{2}O_2 \longrightarrow R{-}\overset{\overset{O}{\|}}{C}{-}OH \quad \text{(catalyst)}$$

Aldehyde oxidized	Product	B. P.
Butyraldehyde	Butyric acid $CH_3{-}CH_2{-}CH_2{-}\overset{\overset{O}{\|}}{C}OH$	163°
Crotonaldehyde	Maleic anhydride 	202°

Aldehyde oxidized	Product	B. P.
Crotonaldehyde	Crotonic acid $CH_3{-}CH{=}CH{-}\overset{\overset{O}{\|}}{C}{-}OH$	185°
Acetaldol	B hydroxy butyric acid $CH_3{-}\underset{\underset{OH}{|}}{CH}{-}CH_2{-}\overset{\overset{O}{\|}}{C}{-}OH$	Dec.

Peracids made in the non-catalytic oxidation are difficult to separate from the aldehyde. They have been shown to be intermediates in the formation of the acids, and they must be handled very carefully to avoid explosions.

The unsaturated aldehydes have been oxidized to the corresponding acids, but the yields, in general, are not as good. Their conjugated double bonds make them useful intermediates for many chemical syntheses.

The aldols might also be oxidized under certain conditions to 3-hydroxy acids.

Maleic anhydride can be made in good yields by the vapor phase oxidation of crotonaldehyde.

Acetaldehyde, as a dilute solution in acetic acid, is oxidized to acetic acid by air in the presence of a catalyst. Temperature control is obtained by recycling a large portion of the reaction product through water cooled exchangers. The reactor product is fed into a column where unreacted acetaldehyde, water and low boiling impurities are distilled overhead. The residue from this column is then fractionated to separate the pure product from catalyst and high boilers. The acetaldehyde vapor in the air from the reaction is removed by absorption in water. Acetaldehyde is then stripped from the aqueous solution in the usual manner.

1B. Dehydration of aldols

$$R{-}CH_2{-}\underset{\underset{OH}{|}}{CH}{-}\underset{\underset{R}{|}}{CH}{-}CH{=}O \longrightarrow R{-}CH_2{-}CH{-}C{-}CH{=}O + H_2O$$

Starting material	Product	B. P.
Acetaldol	Crotonaldehyde $CH_3{-}CH{=}CH{-}CH{=}O$	102°
Butyraldol	2 ethyl 2 propyl acrolein $CH_3{-}CH_2{-}CH_2{-}CH{=}\overset{\overset{CH_2{-}CH_3}{|}}{C}{-}CH{=}O$	180° est.

The aldols dehydrate easily and in

The "Master" Contract – GOOD OR BAD?

EVEN before the last war, a definite trend seems to have been established which has become accelerated in recent years—in favor of the so-called "master" contract.

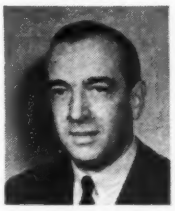
Under this type of contract *all* engineering and construction work to be undertaken at any particular refinery site is placed with *one* engineering contractor—instead of being distributed among several.

From our experience—in the building of complete domestic refineries at Denver, Lake Charles, Salt Lake City and currently at East Chicago, Indiana, plus complete foreign installations made in Palestine and currently contracted for in Brazil, Canada, Argentina and the British Isles—there *are* definite and direct advantages in this method of operation which are probably the reason for the increasing number of "master" contracts being let.

For instance, the "master" type contract offers to the refiner—big or small,

1. ***Concentration of overall process responsibility***
   ... with consequent increase of efficiency of final plant and more profitable employment of refiner's own staff
2. ***Integrated process planning***
   ... providing actual initial capital savings and continued improved operating efficiency
3. ***Coordinated mechanical engineering***
   ... eliminating costly hours of coordinating time and job site alterations
4. ***Uniformity of engineering specifications***
   ... providing economy in maintenance and spare parts inventory
5. ***Centralized purchasing of materials and equipment***
   ... permits allotment of scarce materials in accord with desired completion schedule
6. ***Simplified field administration and accounting***
   ... removing the necessity of duplicate facilities by several contractors in the field and the concurrent extra work at home offices
7. ***Elimination of competition for local labor***
   ... expediting construction and insuring minimum labor costs
8. ***Uniform labor policy at job site***
   ... with resultant improvement of man-hour efficiency
9. ***Maximum economy in use of all labor at job site***
   ... through the flexible interchange of crafts from one unit to another
10. ***Saving in temporary facilities at job site***
    ... by dispensing with duplicate utility lines and housing for tools, supplies and labor
11. ***Reduced tool expense***
    ... through full time use of all tools on various units

by
Warren L. Smith
Vice President of The
M. W. Kellogg Co.



In future advertisements in this series, specialists in each phase of refinery engineering and construction will discuss in detail each of these advantages accruing to the refiner who selects the "master" contract operation.

Our company—M. W. Kellogg—is completely staffed and equipped for refinery and chemical plant design and construction, from the step of laboratory research through the initial operation of completed plants. It periodically issues a publication called the KELLOGGRAM, which describes many of these services. If you are not already receiving it, we will be glad to add your name to the list if you will just drop us a line at 225 Broadway, New York 7, N. Y.

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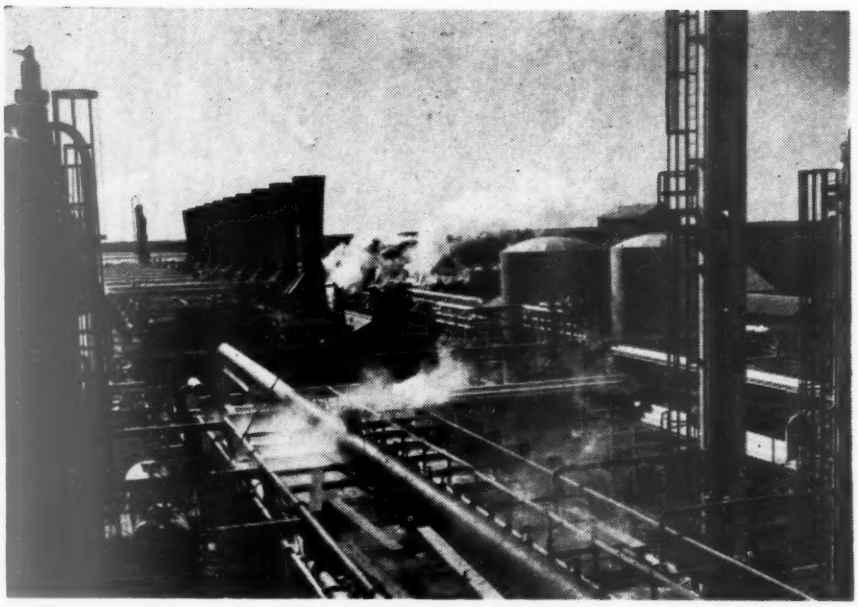
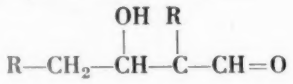


Another view of Chemcel.

good yields to give unsaturated aldehydes. The unsaturated aldehydes are useful intermediates and may be made to polymerize with peroxide catalysts. As they can be made so easily, work on their polymerization may be worth investigation.

Acetaldol readily dehydrates to crotonaldehyde under the influence of heat in the presence of traces of iodine. Acetaldol containing a trace of iodine is fed into a column where acetaldehyde is distilled off. The residue goes to a second column where the crotonaldehyde-water azeotrope comes overhead and inorganic salts out the base. The azeotrope contains 80 per cent by weight of crotonaldehyde.

2B. Hydrogenation of aldols



Starting material	Products	B. P.
Acetaldol	1, 3 butylene glycol	207°
Butyraldol	2 ethyl, 1, 3 hydroxy hexane	270° est.

The aldols hydrogenate in good yields to glycols. The products are useful for making plasticizers, resins, explosives, solvents, and as chemical intermediates.

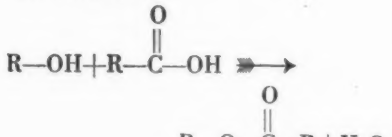
Acetaldol is hydrogenated to 1, 3 butylene glycol at 800 psi and temperatures ranging from 120 to 230 F in the presence of nickel catalyst. The reaction is carried out continuously in a series of tall, small diameter reactors by passing acetaldol with catalyst in suspension cocurrently with a large excess of hydrogen. After cooling the product from the last reactor the excess hydrogen is separated and recycled to provide the agitation necessary to keep the catalyst suspended.

Each reactor is provided with a jacket through which mixtures of steam and water are passed to maintain the temperature of each reactor slightly higher than that of the preceding reactor. The temperature in the first reactor must be kept low because the high acetaldol concentration favors crotonization. A higher temperature is necessary in the last reactor to complete the hydrogenation.

Most of the catalyst fed to the reactors is that recovered from the hydrogenated product by settling and filtration. The make-up catalyst is freshly prepared by treating powdered nickel-aluminum alloy with caustic soda and then washing with water.

The hydrogenated product contains, in addition to 1, 3 butylene glycol, ethanol from hydrogenation of acetaldehyde in the acetaldol feed and butyl alcohol from crotonization and hydrogenation of acetaldol. The purification system consists of an ethanol column, butanol column and two glycol columns. The ethanol is fractionated from the hydrogenated product in the ethanol column. Butanol and water are then fractionated from the mixture in the butanol column. The residue from the butanol column is then distilled in the glycol columns under vacuum, leaving as a residue the higher boiling compounds formed as a result of side reactions in the aldoling process.

4B. Esterfication

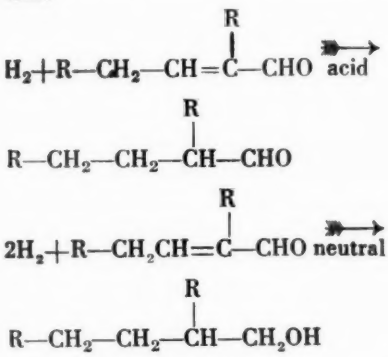


Alcohol	Acid
1, 3 butylene glycol	acetic acid
2 ethyl, 1, 3 hexane diol	butyric acid
butanol	crotonic acid
ethanol	2 ethyl 3 propyl acrylic acid
	maleic acid
	tetra hydro phthalic acid

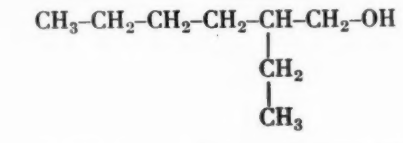
Ethyl acetate is produced by the reaction of acetic acid with ethanol in the presence of sulphuric acid, which catalyzes the reaction. The reaction mixture is fed into a fractionating column from which the ternary azeotrope of ethanol-water-ethyl acetate comes overhead.

This distillate is diluted with water, which causes two layers to separate, the top being nearly pure ethyl acetate. The bottom, which is dilute ethanol, is separated in a second fractionation.

1C. Hydrogenation of substituted acroleins

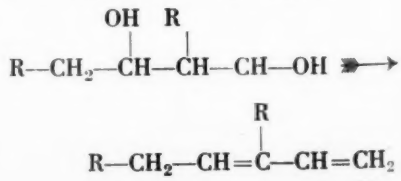


Starting material	Product	B. P. °C.
Crotonaldehyde	Butyraldehyde	75.7
Crotonaldehyde	1 butanol	117.7
2 ethyl, 3 propyl acrolein	2 ethyl-hevanol	183.5



By control of pH this reaction can be made to yield either the alcohol or the aldehyde. The products listed could be reused in a number of the reactions already listed. Butanol, for instance, could be used as a source of higher alcohols, which have such uses as flotation agents, anti-foaming agents, and plasticizers.

2C. Dehydration of 1, 3 glycols



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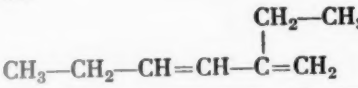
Starting material	Product	B. P.
1, 3 butylene glycol	Butadiene $CH_2=CH-CH=CH_2$	1°
2 ethyl 1, 3 hydroxy hexane	2 ethyl 1, 3 hexadiene	100° est.



The formation of butadiene by the dehydration of 1, 3 butylene glycol has been studied extensively. Other 1, 3 glycols may be dehydrated in a similar manner. The dienes are used in the Diels Alder synthesis of cyclic compounds. Dienes form useful polymers and are useful chemical intermediates because of the ease with which they add with compounds having an active hydrogen.

One, three butylene glycol is dehydrated to 1, 3 butadiene in the vapor phase at atmospheric pressure and about 500 F in the presence of catalysts. The reaction absorbs heat. Glycol and recycled butadiene are fed into a gas-fired furnace where the glycol is vaporized and the butadiene and glycol vapors superheated to the reaction temperature. The reactors are fintube exchangers in which the heat absorbed by the reaction is provided by hot inert gas passing through the fintubes. Catalyst is deposited on the fins.

By so conducting the reaction, the temperature drop is minimized. This is desirable since the highest yield is obtained within a small temperature range. Too low a temperature causes a low reaction rate, while the upper temperature is limited by the polymerization of butadiene to oil.

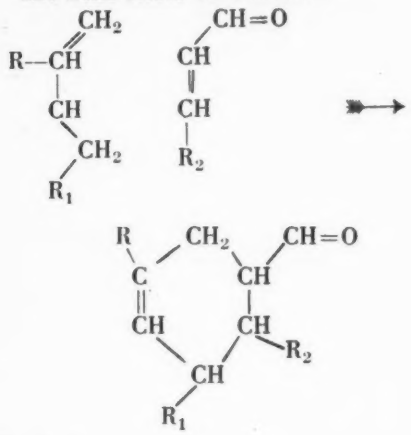
The vapors from the reaction are cooled to room temperature, which causes the unreacted glycol, butenol, water, and oil to condense. Most of the butadiene is recycled to the reactor for purposes of dilution. The butadiene product is finally washed with water to remove traces of aldehydes and then liquefied by compression. The butadiene is then fractionated at 100 psig from higher boiling impurities always present in very small amounts.

The products condensed from the reaction vapors are fed into a vacuum column where oil, water, and butenol are fractionated from the unreacted glycol, which is then fractionated under vacuum from high boiling material. The mixture of oil, water, and butenol is washed with water in a disk and ring extractor to recover the butenol from the oil. Butenol is fractionated from the aqueous solution and returned to the reactor since it is an intermediate product of the overall reaction.

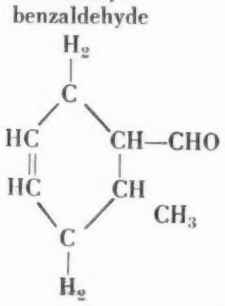
☆ ☆ ☆

Russia is said to contain vast potential oil reserves and yet it needed 50,000 barrels a day more than it had. Russia produced in 1947 about 520,000 barrels daily, but used 570,000 barrels daily. The shortage was partly made up by imports from European countries and the United States.—*The Petroleum Data Book*, Dallas, Texas.

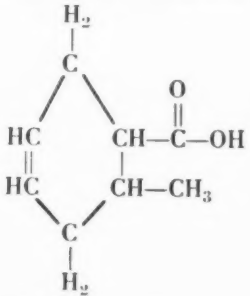
1D. Diels Alder condensation



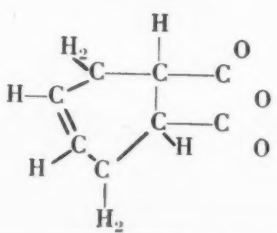
Starting material	Product	B. P. °C.
1, 3 butadiene and crotonaldehyde	1, 2, 3, 6 tetrahydro 1 methyl benzaldehyde	79 (10)



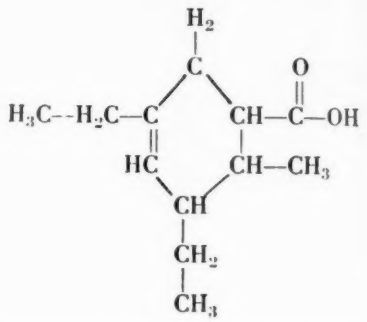
Starting material	Product
1, 3 butadiene and crotonic acid	1, 2, 3, 6 tetrahydro 2 methyl-benzoic acid



Starting material	Product
1, 3 butadiene and maleic anhydride	△ 3 tetra hydro phthalic anhydride



Starting material	Product
2 ethyl 1, 3 hevadiene and crotonic acid	1, 2, 3, 6 tetrahydro 2 methyl 3, 5 diethyl benzoic acid



This reaction is a general one and proceeds with the unsaturated acids, vinyl ketones, and substituted acroleins as well. It involves the combination of two compounds, both having conjugated unsaturation, to give a singly unsaturated ring compound.

Products having a wide range of physical and chemical properties can be made. The products are cyclic aldehydes, acids, and ketones and could be used over in a number of the earlier described operations.

Butadiene can be made to react with crotonaldehyde by passing a mixture of the two through a reactor at about 100 C. About 30 per cent of the reactants are converted to 5-methyl—$\triangle^3$—tetrahydrobenzaldehyde. The unreacted butadiene is condensed from the vapor phase by cooling and is then recycled. The unreacted crotonaldehyde is distilled from the product and recycled.

All materials used in the illustrations above are produced from hydrocarbon gases. Flow sheets could be prepared showing the reactions of the same chemicals with ketones, acetylene, hydrogen cyanide, ammonia, and other reactive chemicals. A very wide variety of compounds could be prepared by using these additional materials.

The relatively short history of commercial organic synthesis has not induced prolific exploration into the multitude of product possibilities. Commercial encouragement is lacking in many instances, for the present basis for organic chemical development usually depends on the industrial demand. Demand hardly over reaches real significance until the products enter the low cost market; however, it is hoped this discussion will serve to emphasize the tremendous future of products occupying secondary reaction positions, but still having as their primary origin natural gas hydrocarbons.

I wish to acknowledge the material assistance provided by S. B. Jeffries, research chemist, in preparing this article.

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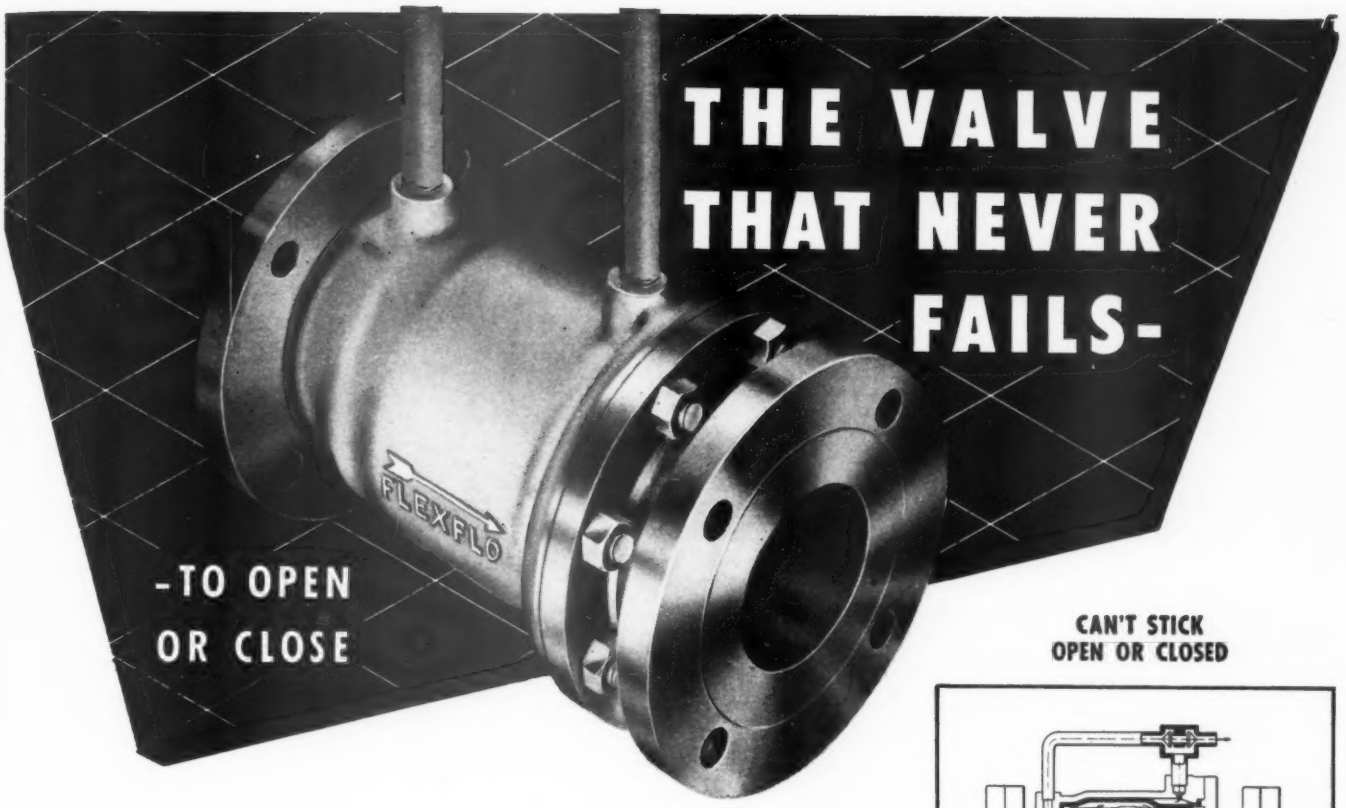

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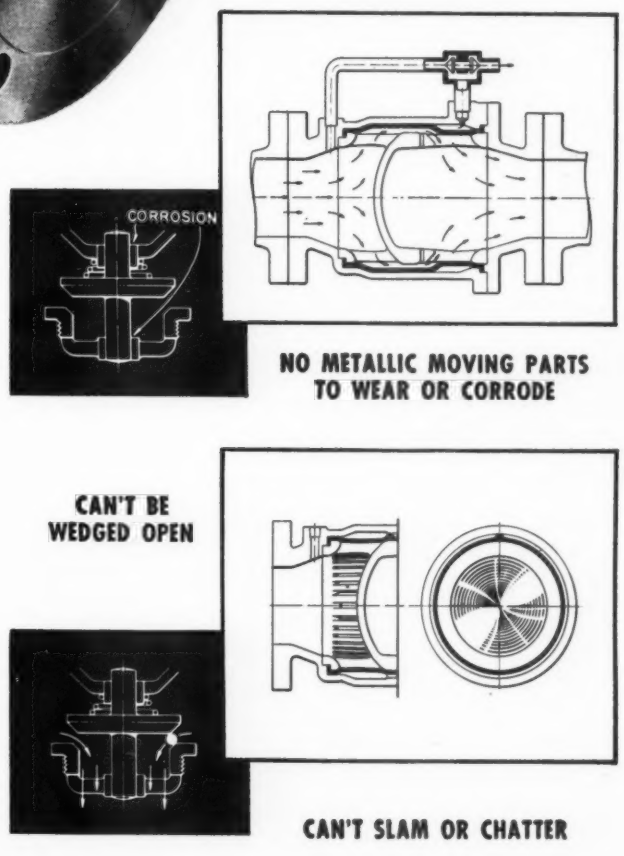

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Developments in instrumentation in analysis*

By RALPH H. MULLER

To determine 11 elements in 45 sec is a new record, we believe, but it seems to be indicative of what may be expected in the future for the routine spectrographic examination of metals and alloys. An instrument for the automatic spectrographic analysis at such prodigious speeds is the Quantometer, now available from the Applied Research Laboratories of Glendale, California.

● **The Quantometer.** The Quantometer is a special instrument designed specifically for its function of direct reading. The accuracy is superior to ordinary spectrographic methods, which employ the photographic process, although the Quantometer's lower limit of measurement needs about three times the concentration of an element required by the best spectrographic methods.

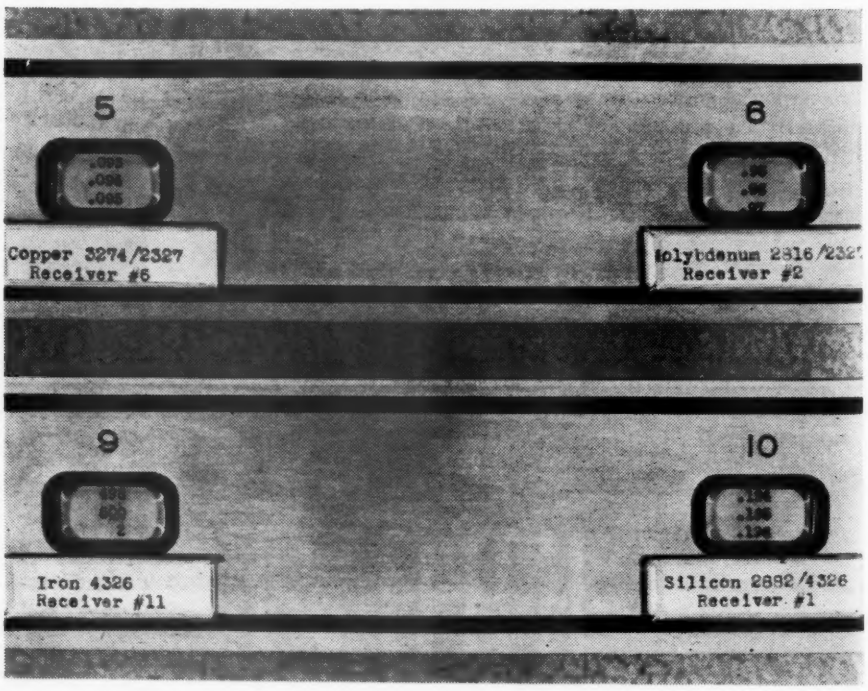
The spectrometer unit of the Quantometer is provided with a source stand and bench, primary slit, and a choice of diffraction gratings. High resolution original gratings of 1 by 2 in. surface can be supplied in two types each having a radius of curvature of 150 cm. One ruling of 24,000 lines per inch covers the range of 2000 to 6000 A. with a dispersion of 6.9 A. per mm. Another grating with 36,000 lines per inch provides a range of 2100 to 4700 A. with a 50 per cent increase in dispersion and resolution. Beyond this stage, the Quantometer differs from conventional spectrographs in that it is designed with a long focal curve along which slit-covered receivers are placed in order to intercept any desired spectral lines. As many as 12 receivers can be moved into position without serious interference between them, such that several lines close together in the spectrum can be measured simultaneously. The radiation entering each receiver falls on an electron multiplier phototube. The output of this tube, which is proportional to the light intensity, is inegrated and converted into a series of electrical impulses. These impulses, after suitable amplification, are passed on to the recording console. The results appear as percentages of each element, exhibited on a printed tape.

The receiver assembly of the Quantometer is shown in Fig. 1. Each receiver consists of a mechanical and electrical assembly that moves along the ways and supports the mirror and slit components. The electrical unit is readily removable for inspection or repair and contains the multiplier phototube, its voltage divider, and the intergrating and amplifying circuits. The positioning of each unit is accomplished by precision screws turned from a control panel at the side of the spectrometer. A dial and indicator permit the correct setting on a desired spectral line with a few Angströms by means of a wave length *vs.* dial-setting graph. Final adjustment is made in less than a minute with a line profiling meter.

The maximum complement of receivers consists of three receivers mounted on each of four bridges, or a total of 12. Since one of these is scanning an internal reference line, the remaining 11 can

FIG. 1. Receiver assembly of Quantometer.

FIG. 2. Front of console. Direct recording of per cent composition.



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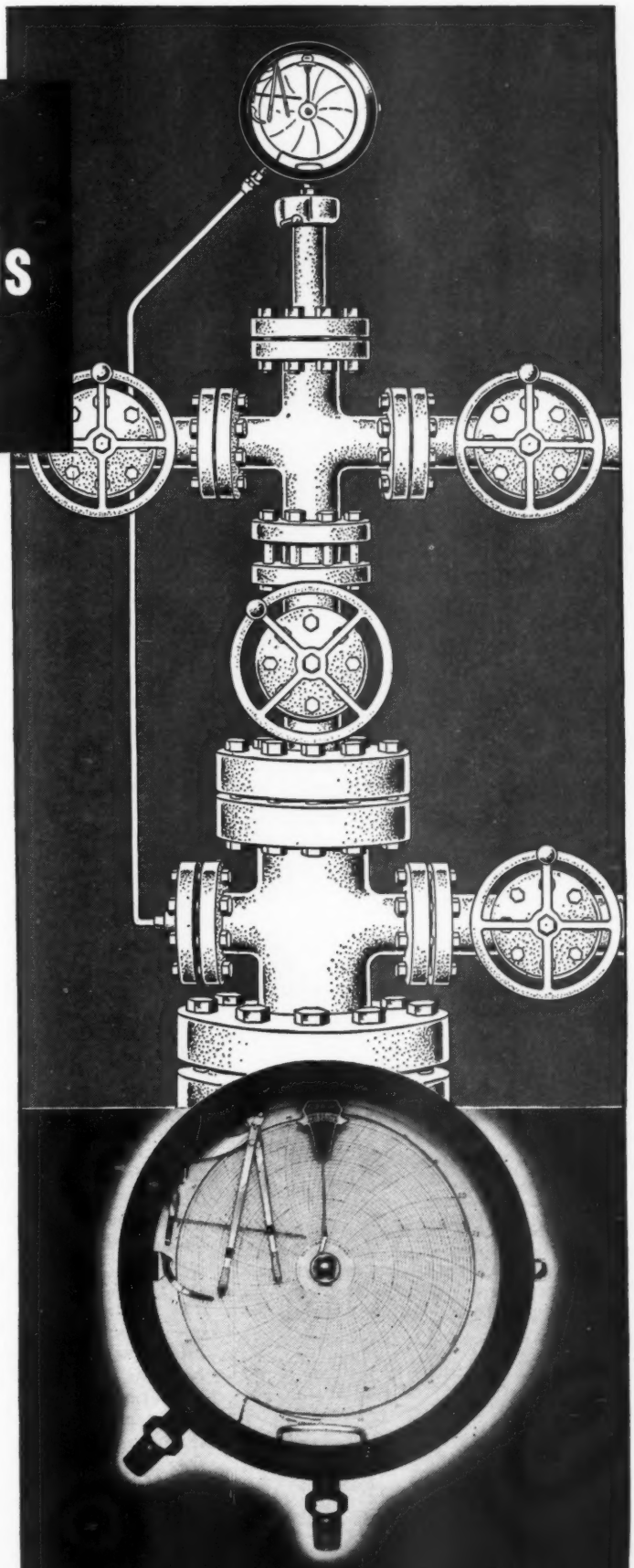
KEEP ON TOP of Significant Trends in Rock Pressure



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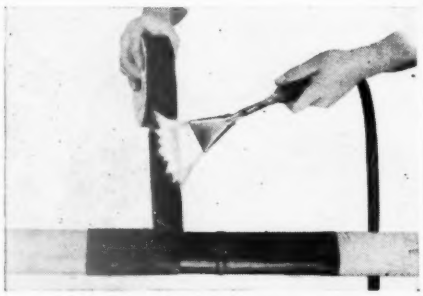
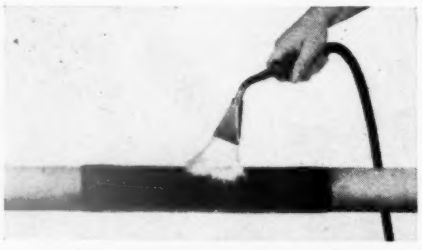


STEP 2—Start wrapping TAPECOAT where kraft paper has been removed. Flash flame of torch *lightly* on TAPECOAT to bleed its coating. Secure double thickness of TAPECOAT by overlapping slightly more than half the width of the tape.



STEP 3—Finish wrapping TAPECOAT. When wrapping is completed, flash the torch flame over entire TAPECOATED section to bleed coating to a shiny surface.

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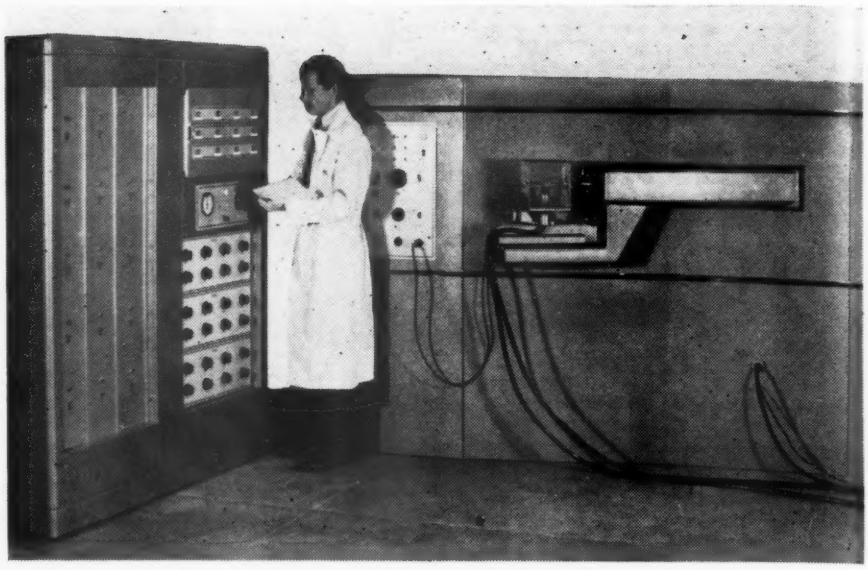


FIG. 3. General view of Quantometer installation.

simultaneously measure 11 other elements.

The final analytical results are supplied by the integrating recorders. These consist of motor-driven electromagnetic counters that drive 50-in. tapes on which percentages of the various constituents are printed. These values appear in little windows of apertures in the front of the console (Fig. 2). After a reading has been noted by the operator, the tape can be restored to its original or zero position by pushing a button.

● **Analytical procedure.** The analytical procedure is simple. One receiver is placed so that it scans a line of the internal standard element. The sensitivity of this monitoring receiver is so adjusted that it completes a cycle of 500 counts during the sparking period, say 25 sec. Other receivers, which are scanning appropriate lines of the elements that are to be determined, are accumulating counts during this interval in proportion to the amount of those elements present. The sensitivity of each recorder is adjusted until the correct percentage of each element is indicated when a standard sample is being sparked. The sensitivity adjustment can be made with ease and precision by means of a coarse and fine tapped-switch control. A hundredfold variation in receiver sensitivity can be made in steps of 0.3 per cent. When the calibration procedure is finished, the operator can assure himself at any time that everything is in order, merely by sparking the standard sample. At the conclusion of the sparking period, the percentage of each element appears at the appropriate window.

● **Advantages.** Several advantages over the conventional photographic method are apparent, of which speed is one. A second is the wide range of relative line intensities that can be accommodated. A third advantage is the fact that variations in contrast as a function of wave length do not arise, because the photomultiplier cells have a linear response with intensity at all wave lengths.

Additional refinements include a switching system that permits the operator to terminate the recordings on certain lines, while others are in progress. This is especially convenient for elements which have short "spark-out" times. Also, several receivers may be used separately or simultaneously as internal standard receivers, each controlling the termination of its own group of receivers. This is useful when the instrument may be called upon to analyze two or three different alloys at a moment's notice.

A general view of a Quantometer installation is shown in Fig. 3, with excitation unit and spectrometer on the right and the recording console on the left. The best practices of electronic engineering are to be found in the console, with multiple channel units, readily accessible and removable for inspection. Convenient gang cables with multipronged aircraft connectors are freely employed. All critical power supplies are controlled with Sola voltage regulators and, in addition, critical high voltages for amplifiers and multiplier tubes are electronically regulated.

The manufacturer has had three years' experience with the Quantometer, during which extensive data have been accumulated to establish the precision and reliability of this instrument. Rather convincing evidence is at hand to indicate that where a large amount of repetitive work is to be done, the instrument is likely to pay for the cost of installation in a very short time, and that many metallurgical processes are likely to be radically changed as a result of its widespread use.

We have often been rebuked for implying that much routine analysis of the future would be a matter of "putting a sample in a hopper and having the answer printed on a ticket." Technically, that attitude seems to require no further defense; it is merely a matter of expediency, and, on occasion, a necessity.

★ ★ ★

Notes on the initial operation and test run of 100-octane aviation gasoline plant

By UTAH TSAO, The Lummus Company

Abstract. Most of the 100-octane aviation gasoline plants include a catalytic cracking unit, an alkylation unit, and a butane isomerization unit. This paper describes the initial operation and the test run of a 100-octane aviation gasoline plant in Houston, Texas, which consists of two thermofor catalytic cracking units, one UOP hydrofluoric acid alkylation unit, and one UOP butane isomerization unit. A brief description of the processes involved are presented. The testing of various equipment and the procedure of bringing the units on stream are described. Some mechanical and chemical engineering problems encountered during the initial operation are discussed. The test runs are usually conducted either to procure process data or to check a contractor's guarantee. The method of conducting a test run is described. The possible complications of a test run, the means of calculating the yields, and the analysis of data are discussed.

● **Introduction.** Since 1935 the importance of 100-octane aviation gasoline has greatly increased every year. This production has grown from a few thousand gallons a year to several billion gallons, so that at the end of World War II the daily production of 100-octane aviation gasoline reached 20,000,000 gal. The 100-octane aviation gasoline of recent years is a blend of several components, whose type and amount depend on their individual and blending characteristics. The major components and their processes of manufacturing are shown in the following:

	Components	Processes of manufacture
(1)	Straight run naphtah	Fractionation of selected crudes
(2)	Conversion naphtha	Houdry catalytic cracking Thermofor catalytic cracking Fluid catalytic cracking
(3)	Cumeme	Alkylation of benzene
(4)	Alkylate	Alkylation of light olefins with isomerization of butane
(5)	Isooctane	Hydrogenation of di-isobutylene
(6)	Isopentane	Fractionation of natural gasoline, isomerization of normal pentane
(7)	Tetraethyl lead	Organic synthesis

Straightrun and conversion naphthas are classified as base stocks; cumene, alkylate, and isooctane as high octane blending agents. Isopentane is used to make up the required vapor pressure of the finished gasoline and tetraethyl lead is used as octane booster. Depending upon the practice of the individual refiner the number of combinations of blending the above components together to make the 100-octane gasoline is enormous. A very common blend is as follows:

Straight run naphtha—15 per cent,
Conversion naphtha—45 per cent,
Isopentane—10 per cent,
Alkylate—30 per cent,
with 4.6cc tetraethyl lead to gallon of gasoline.

From the above tabulations we can readily see that the conversion naphtha is the major component for the blending of 100-octane aviation gasoline. The Houdry catalytic cracking process, which utilizes the fixed bed catalyst, produced most of the conversion naphtha during the early part of the war. The process is made semi-continuous by an automatic synchronized valve-timing system switching multiple catalyst cases from onstream to purging and regeneration or vice versa. The development of thermofor catalytic cracking and fluid catalytic cracking processes overtook the production of Houdry process during the latter part of the war. Both processes are continuous with moving catalyst operation, having one chamber for the reaction and another for regenerating the catalyst. The thermofor process uses pelleted, chemically treated natural clay or synthetic catalyst and the fluid process uses pulverized chemically treated natural clay or synthetic catalyst. The movement of catalyst in the former process is accomplished by specially designed vertical lift bucket-type elevators, while in the latter process by blowers using the principle of fluidizing by introduction of vapors to the solid stream for creating a density difference.

The regeneration of catalyst in all three processes is accomplished by burning the coke on the catalyst with air. In the Houdry process the heat of combustion is removed by a molten salt transfer system that supplies heat during the cracking cycle; in the thermofor process by steam generating coils in the multiple zone therfomor kiln; in the fluid process by circulating catalyst from and to the regenerator through heat exchangers. The fractionation systems following the reactors in all three processes are practically identical. The flow diagrams for the thermofor and the fluid processes are shown in Fig. 1. The yields of the three processes are very similar under comparable operating conditions. Typical operating and yield data for a thermofor unit with converted solid bed are shown in Table 1.

● **Description of the plant.** For a large, complete 100-octane aviation gasoline plant the catalytic cracking unit is indispensable to produce the base stock, olefins and butanes, the alkylation unit to produce the alkylate, and the isomerization unit to produce isobutane for the alkylation unit. The 100-octane aviation gasoline plant to be described was built by Lummus in Texas for a governmental agency and was completed in June, 1944. The plant has a capacity to blend 5300 bbl per day or almost 250,000 gal per day of 100-octane aviation gasoline. The block flow diagram of the plant is shown in Fig. 2.

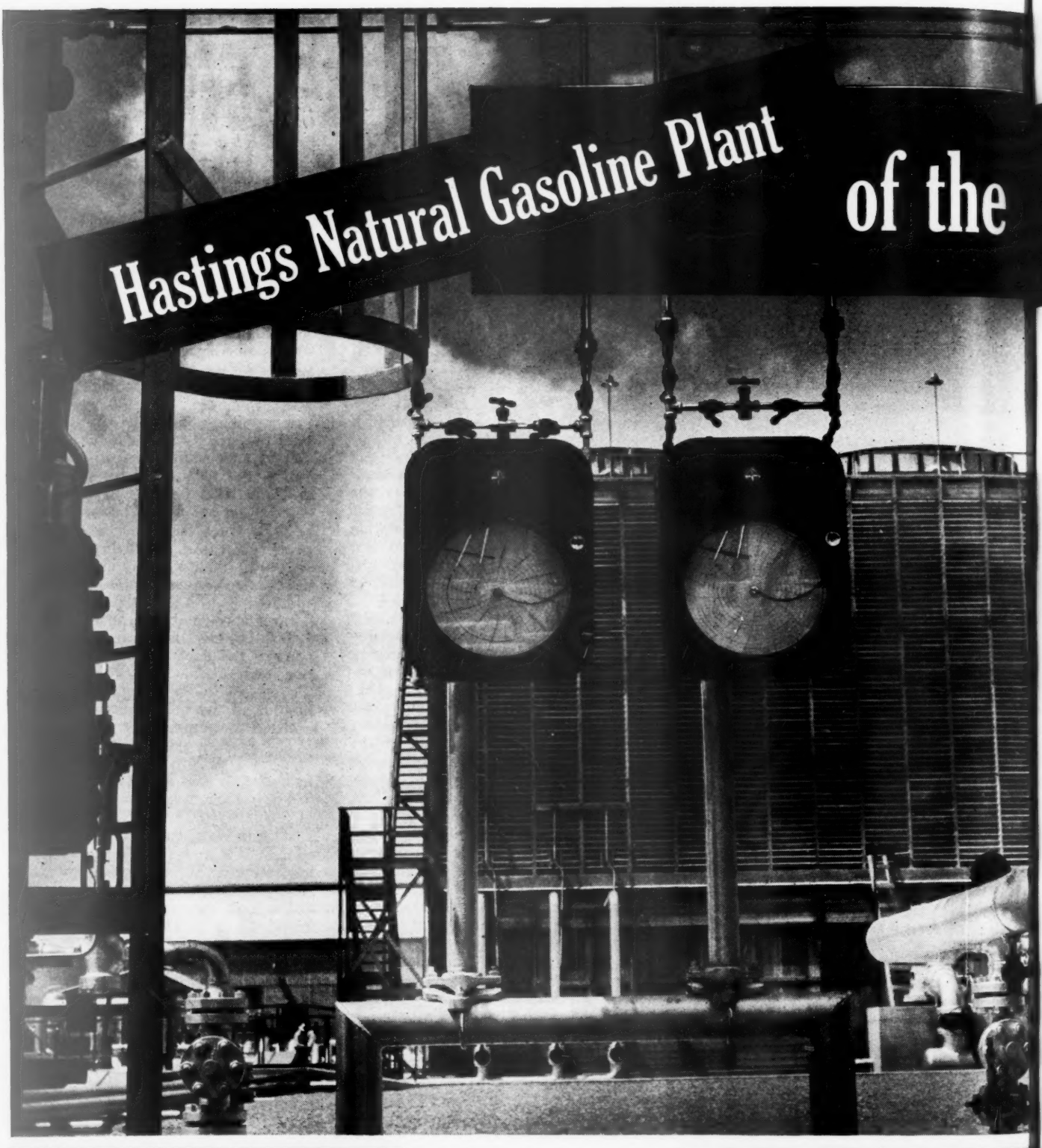
The catalytic cracking units installed in this plant are of the moving bed type comprising two duplicate units using natural clay catalyst. The first unit of 10,000 bbl per day charging capacity receives the gas oil charge. The gasoline made in this unit is then charged to the second unit for retreating and the product of aviation base stock is fractionated therefrom.

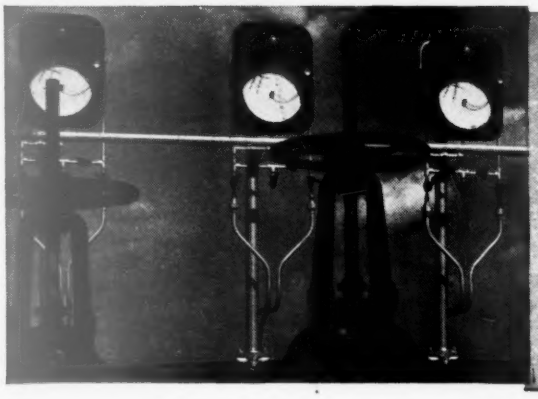
The process used for the alkylation unit is a UOP process using anhydrous hydrofluoric acid as catalyst. A simplified flow diagram is shown in Fig. 4. The olefins charge is caustic washed and dried with bauxite drier and then pumped into the contactors with the isobutane recycle. The contactors are Stratford powered-mixers in which the hydrocarbons and anhydrous HF are mixed violently. The reaction temperatures are maintained around 100 F and the pressure around 110 psig to keep the hydrocarbon in the liquid form. The hydrocarbon-catalyst ratio is maintained at approximately 1:1, and isobutane olefin at about 9:1. The effluents from the contactors pass to a settler in which most of the catalyst is separated from the hydrocarbons and recycled to the contactors. A small stream of the catalyst is charged continuously to an acid purification system where tar and water are removed. Purified HF is returned to HF storage for reuse in the system.

The hydrocarbon liquid separated out in the settler is passed to the HF stripper where all but traces of catalyst are removed and returned to the settler. The bottoms from the stripper are passed to the bauxite treater where bauxite removes the last HF, which is combined with the hydrocarbons. The treated hydrocarbon mixture is fractionated in a deisobutanizer where isobutane and lighter hydrocarbons are removed. The dried isomerized product stream from the isomerization unit is also charged to the deisobutanizer for the separation of isobutane and normal butane. The

*Published in *C.I.E. Journal* of Chinese Institute of Engineers, America Section, May, 1947.

Hastings Natural Gasoline Plant of the

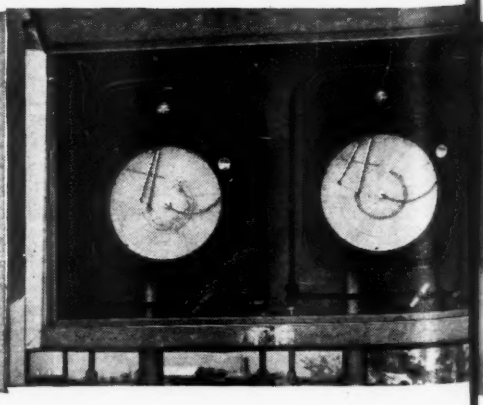




TOP: Dry gas overhead from absorbers

LEFT: Ahead of Compression. Three field mains equipped with Metric Orifice Meters deliver into a header

RIGHT: Twin Metric Orifice Meters on a Hastings lease. One for measuring wet gas from field gathering system, the other for dry gas used in field operations



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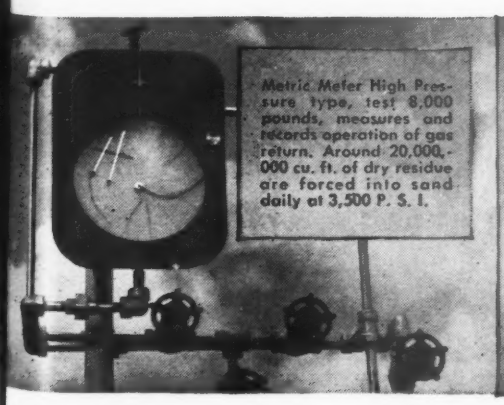
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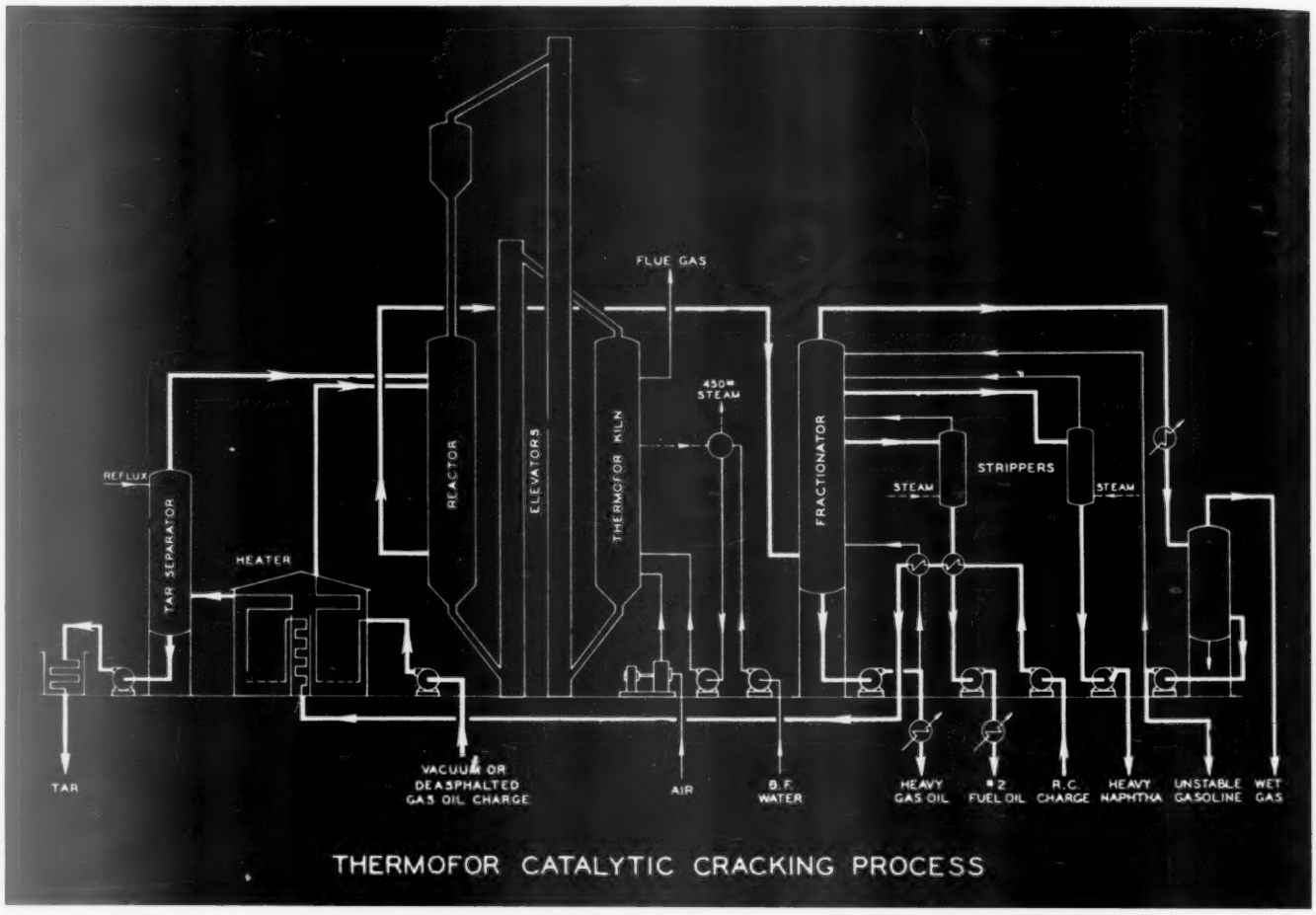
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R.C. CHARGE
HEAVY NAPHTHA
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WET GAS
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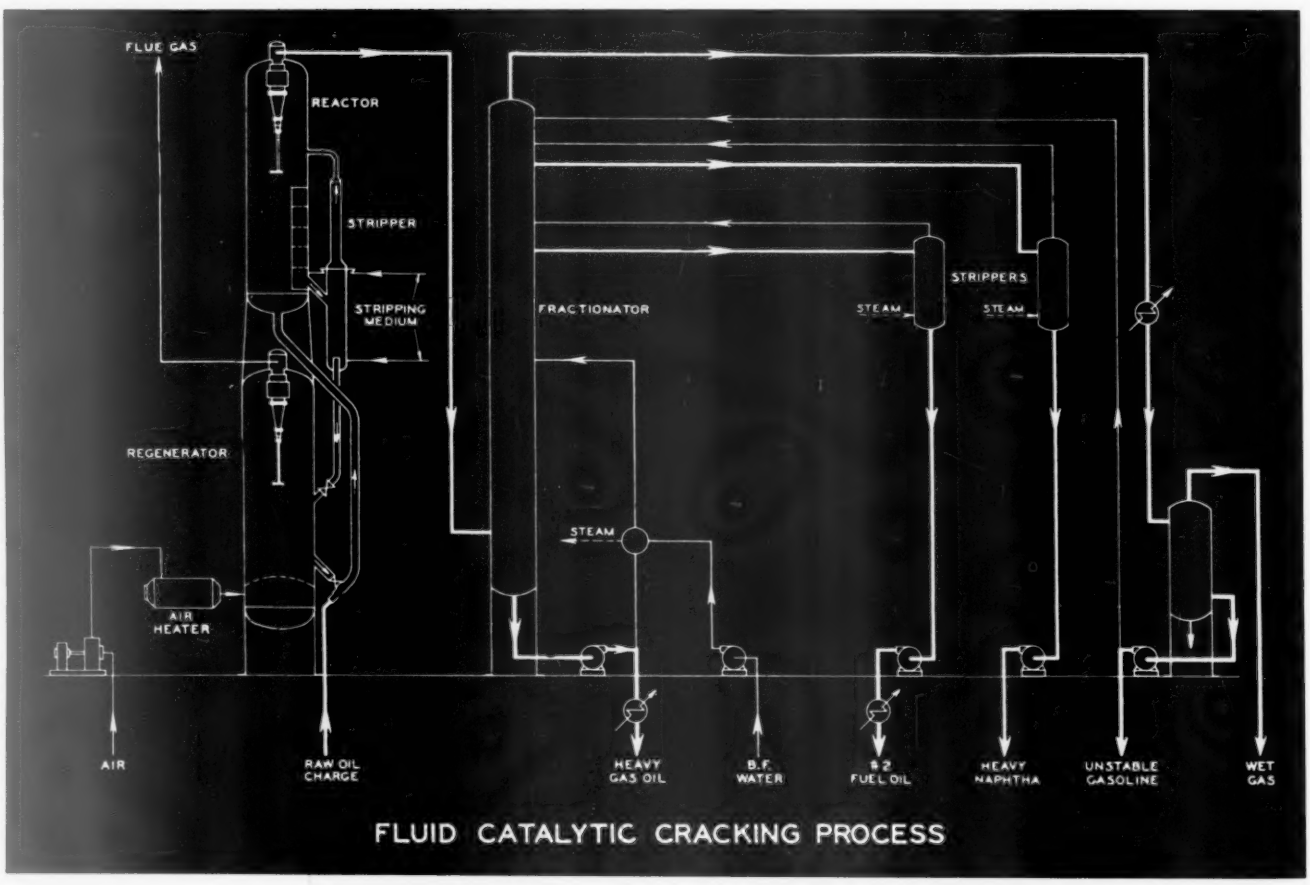
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STEAM
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B.F. WATER
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HEAVY NAPHTHA
UNSTABLE GASOLINE
WET GAS
FLUID CATALYTIC CRACKING PROCESS

FIG. 1.

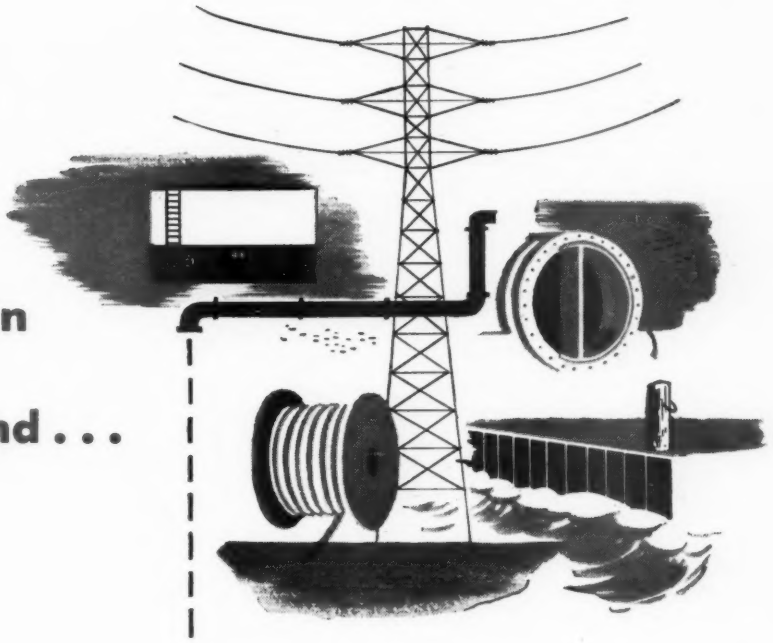

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TABLE 1. Operating and yield data for a TCC cracking unit with converted solid bed for motor gasoline production.

Reactor

Operating conditions		
Depth of reactor bed	22 ft	
Catalyst activity index	30	
Oil to reactor	955 F	
Oil from reactor	965 F	
Catalyst to reactor	990 F	
Average reactor temperature	873 F	
Reactor inlet pressure	11.7 psig	
Pressure drop across bed	130-in. water	
Reactor charge (once-through)	8720 B/D	
Catalyst circulation	110 tons/hr	
Catalyst/oil ratio V/V	2.40	
Space velocity V/V/H	0.91	
Steam with charge weight, per cent	3.72	
Coke on spent catalyst, weight per cent	2.11	
Coke on regenerated catalyst, weight per cent	0.3	
Yields on reactor charge	Vol. %	Wt. %
C_3 and lighter	..	6.39
iC_4	2.92	1.86
iC_4=	1.81	1.24
nC_4=	4.01	2.82
nC_4	2.00	1.39
Total C_4 fraction	10.74	7.31
iC_5	4.25	2.92
C_5=	3.56	2.69
nC_5	1.48	1.07
Total C_5 fraction	9.29	6.68
C_6—400° E. P. gasoline	34.36	30.44
Cycle stock above 400 F	43.89	45.86
Coke	..	3.32
Total recovery	98.28	100.00
Inspection of charge stock		
K factor	11.8	
50 per cent point	628 F	
Gravity	31.5 deg. API	
Aniline No	177 F	

overhead stream from the tower is depropanized and recycled to the contactor as isobutane recycle. The bottoms stream from the deisobutanizer is again treated with bauxite to remove the last trace of fluorine and fractionated in a debutanizer to remove the normal butane which is used as feed to the isomerization unit. The crude alkylate from the bottom of the debutanizer is fractionated in a rerun tower to make the aviation alkylate. The operating and yield data for the HF alkylation unit are shown in Table 2.

The operating capacity of an alkylation unit can be easily increased by reducing the isobutane-olefin ratio in the contactor at the sacrifice of impairing slightly the quality of the alkylate. During the war many units more than doubled their capacities by the above manipulation.

The process used for the butane isomerization unit is also a UOP process using anhydrous hydrochloric acid and aluminum chloride as catalyst. The simplified flow diagram is shown in Fig. 5. The normal butane charge is divided into two streams and one of them passes through the aluminum chloride saturator to be saturated with the catalyst. The two streams join the recycling HCl and enter a reactor packed full with quartz chips in which the catalyst and butane are contacted in the presence of hydrogen chloride. The effluent of the reactor enters a fractionator in which the aluminum chloride remaining in the effluent is removed and recycled to the reactor. The aluminum chloride-free isomerized products from aluminum chloride fractionator are fed to a stripper in which the hydrogen chloride is separated and returned to the reactor. The bottoms from the stripper are washed with dilute caustic to neutralize the last trace of acid in the isomerized products before they are sent to the alkylation unit. The operating and yield data for the isomerization unit are as shown in Table 3.

As hydrofluoric and hydrochloric acids are very corrosive in the presence of moisture, the big problem during the initial operation is to keep the moisture out of the unit to reduce the corrosion and also to keep the acid in the system from leaking through packing or seals of moving joints and instrument connections by a butane flushing system. Hydrofluoric acid is such a hazardous material that extra safety precautions must be taken in handling it. At the beginning the warning of the dangerous character of the acid scared many operators away; however, as the operators have gained experience in handling the acid they tend to be careless, therefore, the safety regulations must be constantly enforced to avoid serious accidents.

● **Operating procedure.** The start-up procedure differs somewhat in details in various plants; however, a general procedure will be described as follows: Before the unit is put into operation all towers and tanks, exchangers, and lines are hydrostatically tested to the design pressure. The equipment under test is filled with water and air is vented off the top. Then the pressure is built up in the vessel to the desired pressure by pumping water into the vessel by a portable hydraulic pump. All pumps must be checked to see that they can be freely turned by hand. A thorough check must be made to be sure that all drains, vents,

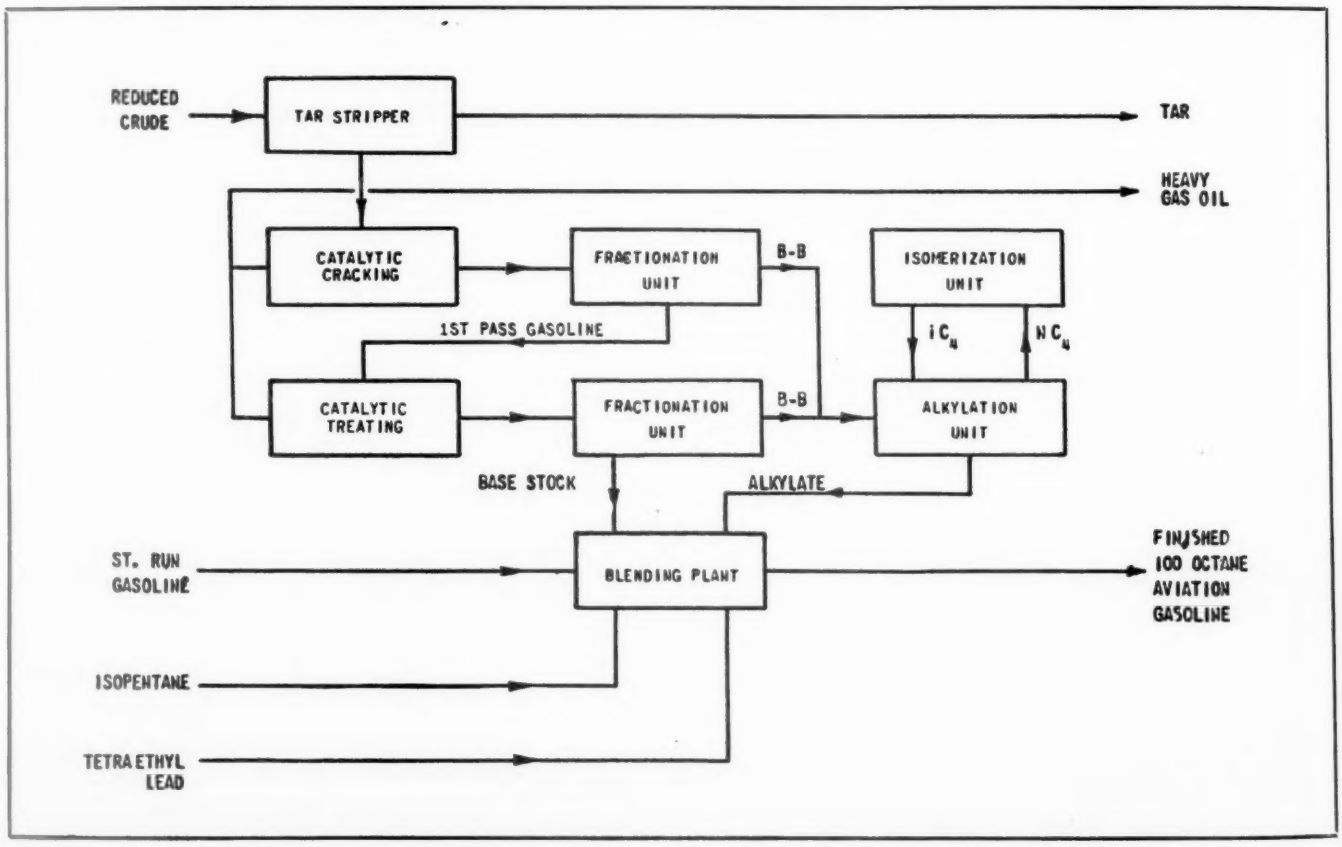
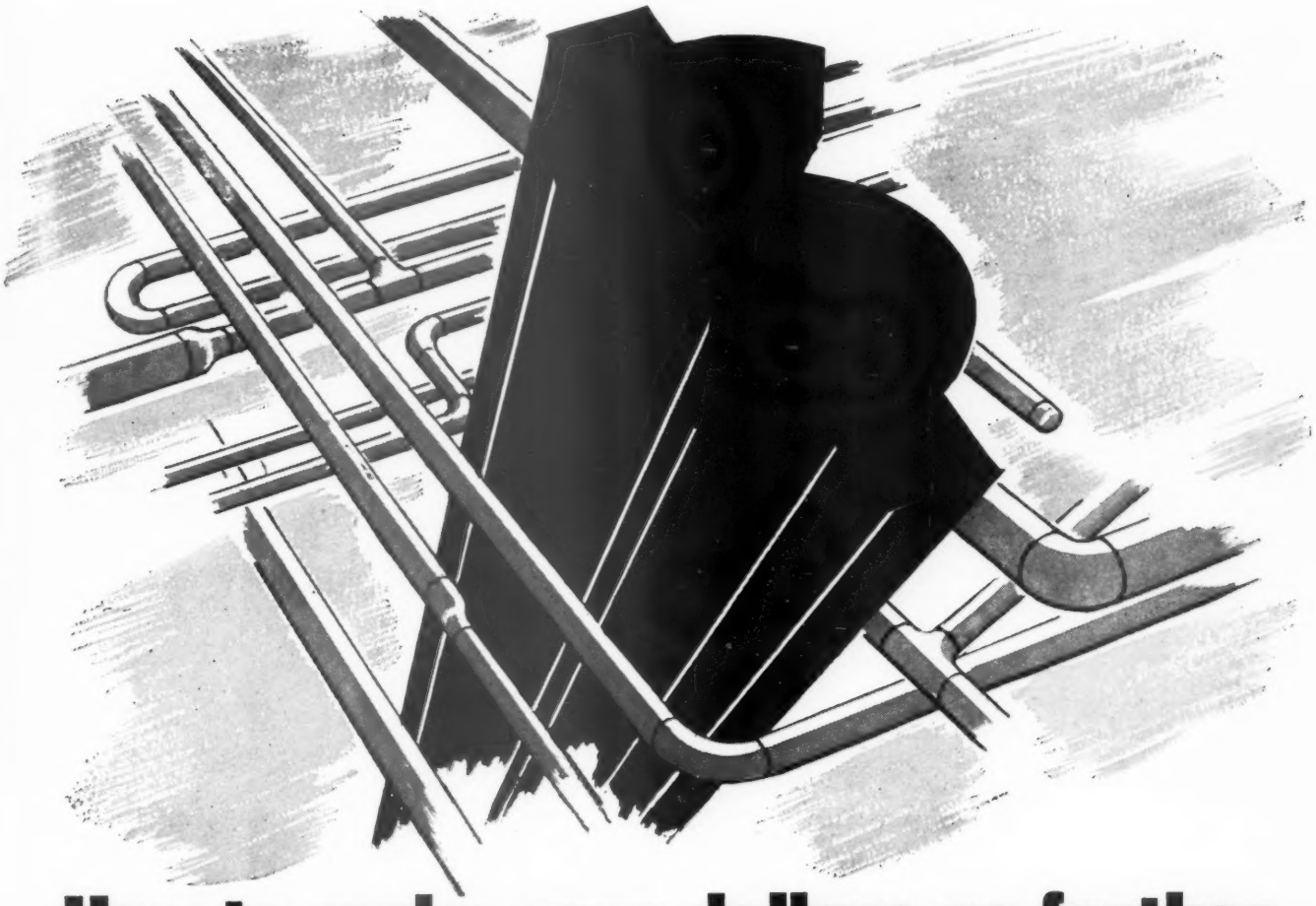


FIG. 2. Block flow diagram of a typical 100-octane aviation gasoline plant.



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try-cocks, etc., are closed and that there are no open ends or blanks in piping. The unit should be left with all valves closed so that each valve can be opened in the correct sequence at the operator's order.

In starting up a cracking unit, equipment is usually lined up to recirculate the oil over and over again and gradually bring the temperature up to the desired level.

The operators on an 8-hr shift in a typical 100-octane gasoline plant are listed in Table 4.

● **Operational problems.** Thermal expansion is a big mechanical problem in a cracking unit. Most of the anticipated difficulties are overcome by the design of equipment learned from past experiences; however, in starting up a plant of new process some unforeseen trouble may occur. The reactor with the clay leg expands more than the 30 in. from room temperature to 900 F. A suitable expansion joint must be provided between the clay hopper and the reactor. Due to the peculiar flowing characteristics of the catalyst pellets an ordinary "U" shape expansion bend cannot be used here. A telescope type expansion joint must be provided between the clay hopper and the reactor. For units with tight fit expansion joints, special attention must be paid to assure their free movement during the starting-up and shutdown period, otherwise damage may be done to the structure supporting the hopper. As there is no pressure at this point, a very loose slip joint, which can be literally described as one small pipe slipped into a larger one, can replace the tight fit expansion joint and make it attention-free.

The flowing clay catalyst will cause excessive corrosion in smooth lines carrying catalyst especially in the lines that are partially filled with catalyst. The best material found satisfactory to protect the line is the catalyst itself. On sloping surface low baffles are installed at such intervals that the catalyst retained between the baffles will cover

TABLE 2. Operating and yield data for an HF alkylation unit.

Charge	2976 B/D
Composition of charge in vol., per cent	
Propane	1.3%
Isobutane	33.5%
Butylenes	28.4%
Normal butane	30.8%
Pentenes	2.5%
Pentanes	3.5%
Isobutane recycle	8500 B/D
Composition on recycle in vol., per cent	
Isobutane	87.9%
Normal butane	12.1%
Heavy alkylate	25 B/D
Light alkylate	2066 B/D
Isobutane/olefin ratio	9.2
Acid/hydrocarbon ratio	2.0
Contactor temperature	100 F
Contactor pressure	110 psig
Composition of acid in weight, per cent	
HF	88%
Water	2%
Hydrocarbon	10%

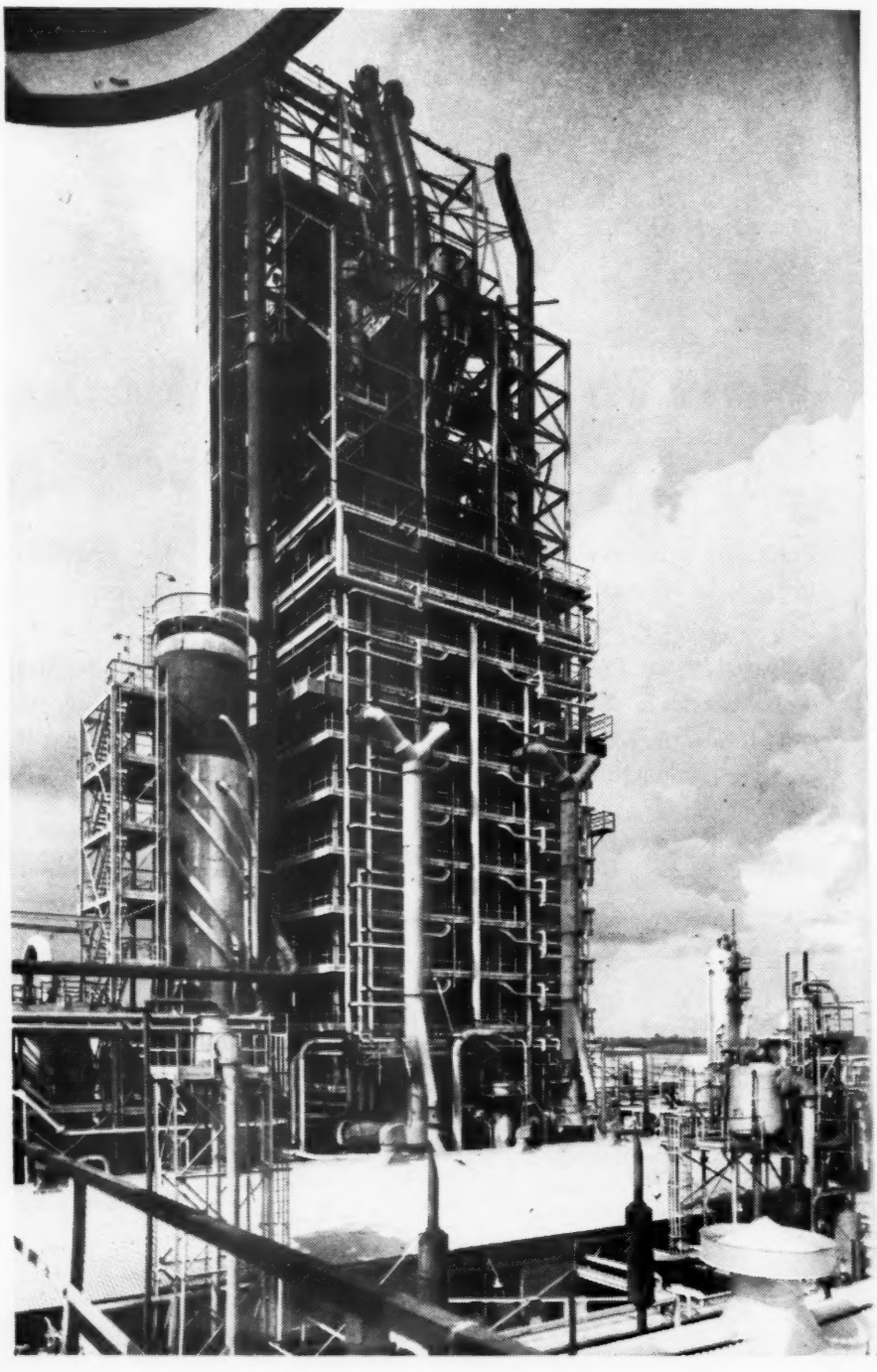
TABLE 3. Operating and yield data for an isomerization unit.

Feed to saturator	687 B/D
Feed to reactor	1991 B/D
Flush	332 B/D
Total feed	3020 B/D
Total plant effluent	2960 B/D
$AlCl_3$ bottoms recycle	355 B/D
Reactor:	
Top temperature	206 F
Outlet temperature	200 F
Pressure	205 psig
$AlCl_3$ tower:	
Top temperature	206 F
Outlet temperature	200 F
Pressure	225 psig
Vol. per cent iC_4 in feed	5.0%
Vol. per cent iC_4 in effluent	39.4%
Isobutane produced	1015 B/D
Average saturator temperature	178 F
$AlCl_3$ consumed	1031 lb/day
Gallons of iC_4 per lb $AlCl_3$ consumed	41.4

TABLE 4. The operating personnel of a 100-octane gasoline plant: one shift foreman in charge of the whole plant.

Cracking section	*Light ends section*	*Boiler house*
One head stillman	One head stillman	One water treating man
(a) Cracking units	(a) *Feed preparation unit*	One boiler fire man
Two junior stillman	One junior stillman	
One kiln man	Two helpers	
One fire man	(b) *Alkylation contractor section*	
One board man	One junior stillman	
(b) *Compressor house*	Three helpers	
	(c) *Alkylation fraction section*	
One compressor man	One junior stillman	
One helper	One helper	
(c) *Pump house*	(d) *Isomerization unit*	
One pumper	One junior stillman	
One helper	One helper	
	(e) *Pump house*	
	One pumper	
	One helper	

FIG. 3. Large catalytic cracking unit built by Lummus in Texas.



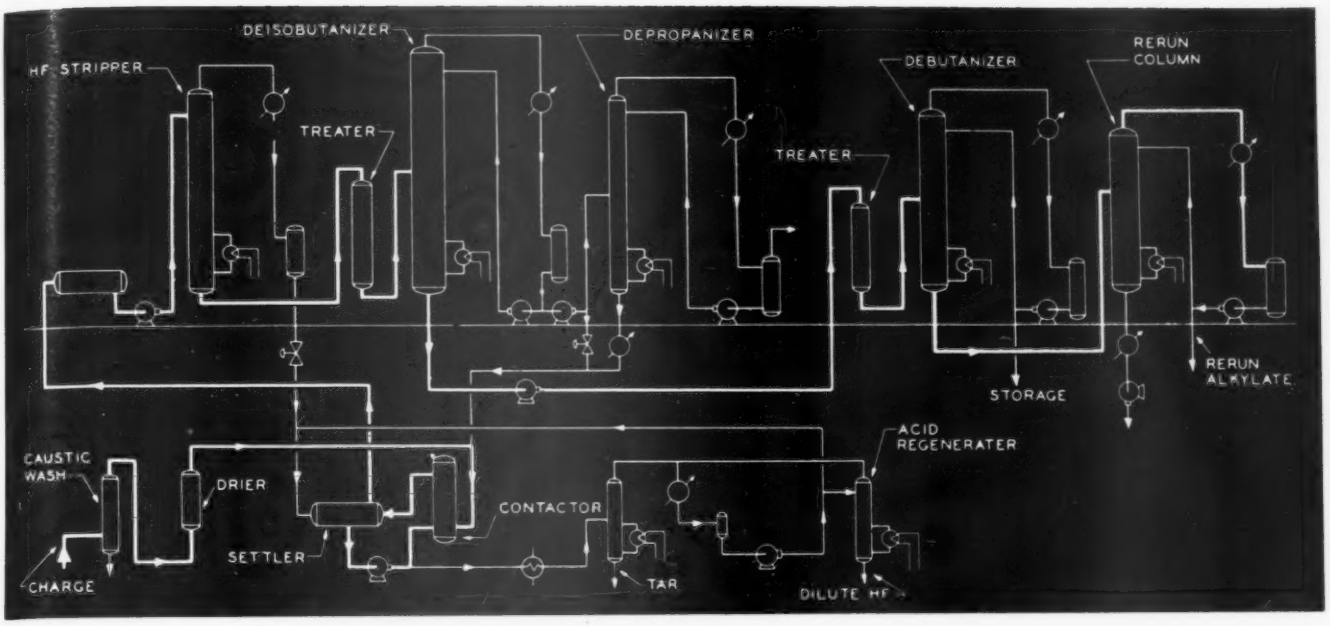


FIG. 4. Flow diagram of HF alkylation unit

up the surface of the line and then the retained catalyst serves as rollers for the flowing catalyst. At turning bends of vertical lines extra space is provided to hold a pot of catalyst that will protect the wall from the pecking of the rapidly moving pellets.

Moisture is such a common thing that it is often neglected wherever absolute dryness is not stressed as it will not make its appearance until it is condensed into water. Many process troubles can be attributed to this mere negligence, however. For example, during the warming-up period of the initial operation, the clay catalyst in the system must be kept moving all the time, otherwise the moisture driven off from the hot catalyst will be condensed on the colder catalyst, which would turn into mud due to the excessive moisture.

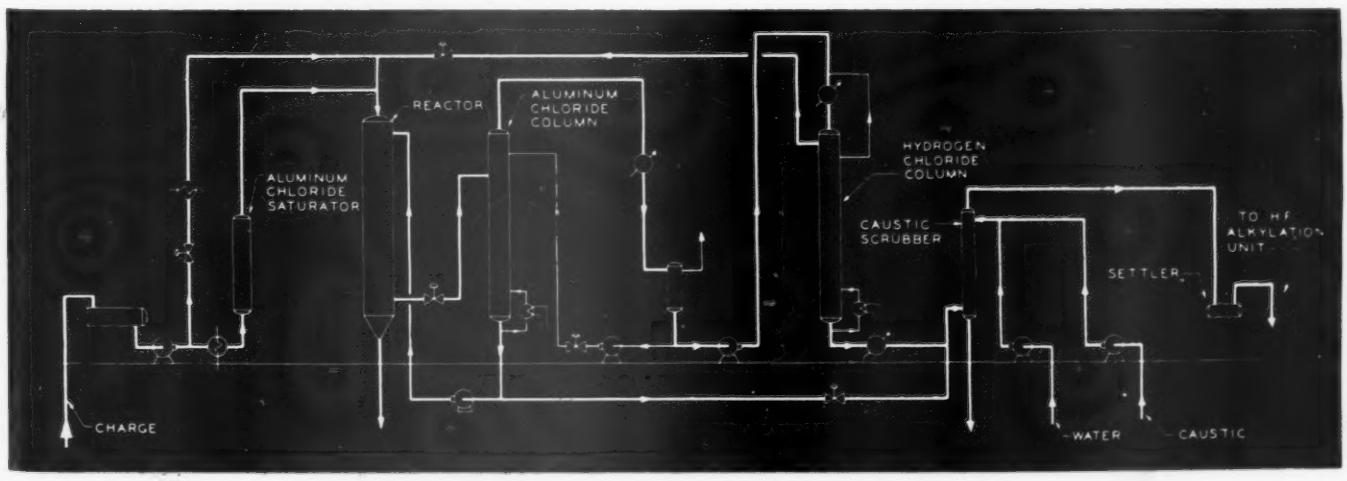
Water can play havoc with light hydrocarbon fractionation tower when it gets into the tower. It will literally choke the tower because the top temperature of the tower may be too low to allow sufficient water vapor to leave the top and at the same time the bottom temperature is too hot to allow the water to reach the bottom before it is vaporized. There is more than one way water can leak into such towers, however. For example, if the overhead reflux accumulator of such tower is not constantly checked for water, excessive amounts of water will be dumped back into the tower through the reflux pump. Sometimes water is separated out at the bottom of the absorber as the entering gas can no longer hold its moisture after the heavier components of the gas have been absorbed. In such a case the bottom of the absorber should be regularly checked for water, otherwise the tower to receive feed from the bottom of the absorber will suffer the consequence of water flooding. Wherever water precipitation is expected it is advisable to install instruments for automatic dumping of water because the saving in the labor and the hydrocarbon loss involved in manual dumping will soon pay for the additional installation cost, and besides there will be less of the human element involved.

● **Test runs.** The test runs are usually conducted either to obtain process data or to check the contractor's guarantee. The methods of conducting a test vary widely according to purpose. The period of a test run may last a few hours to a day to procure process data. It may last weeks to check a contractor's or licensor's guarantee. During a run for procuring process data the operating conditions are maintained as constant as practical to eliminate the error of including extreme condition in the results. But the conditions set for different test runs may cover a wide range in order to find the trend of a certain factor. However, during a test run for testing guarantees the operating conditions may be adjusted frequently to the best advanage in meeting the conditions in the guarantee.

The four important measuring procedures used for a test run are metering, gauging, sampling, and analysis. The test streams are metered and the liquid streams are either metered in line or gauged in tanks after accumulation.

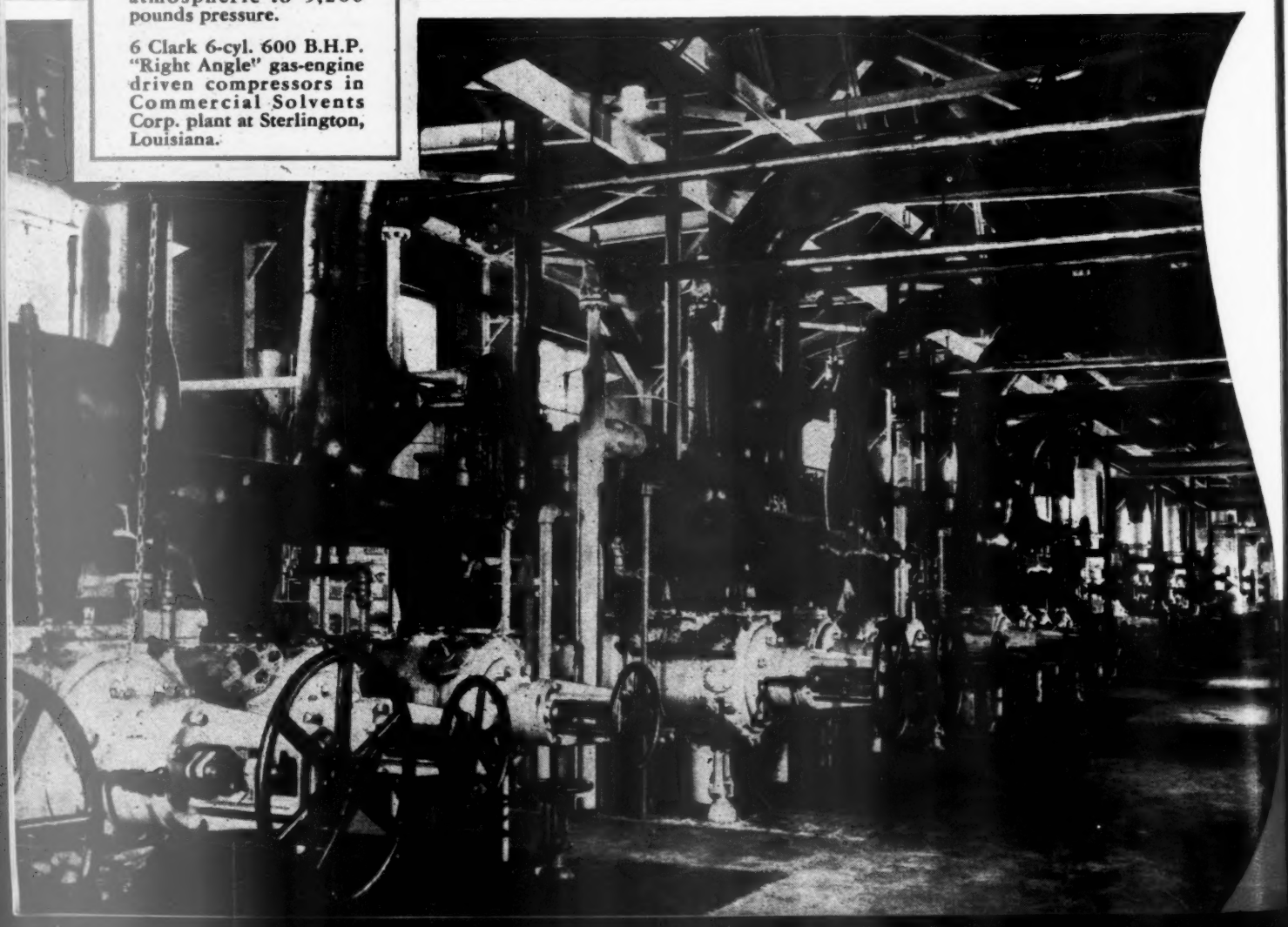
(a) *Metering.* Metering is the most convenient means of measuring and for short test runs it is also most accurate if the meters are calibrated against the

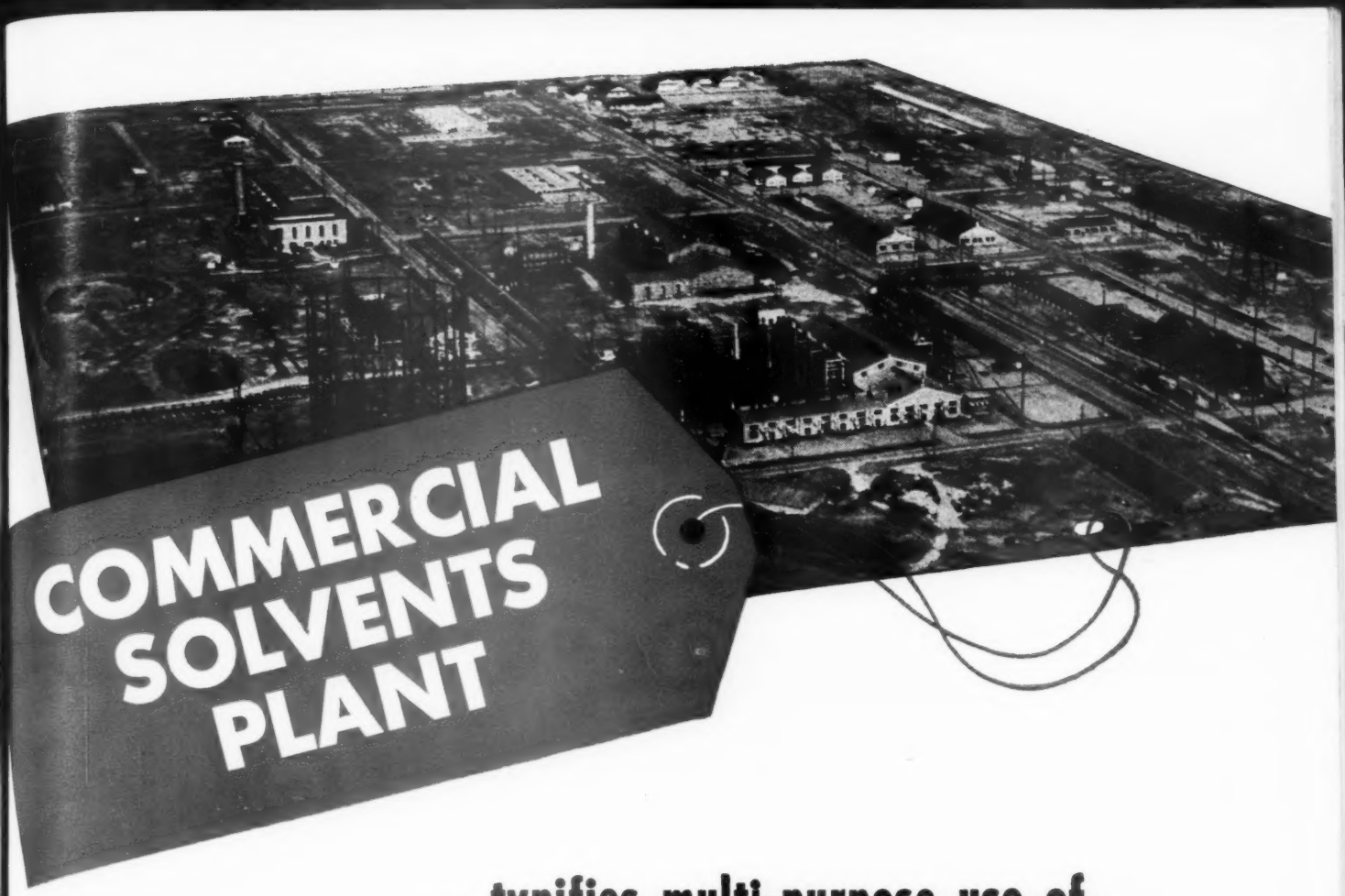
FIG. 5. Flow diagram of butane isomerization unit.



8 Clark 8-cyl. 2790 B.H.P. steam-engine-driven compressors pump gas from atmospheric to 5,200 pounds pressure.

6 Clark 6-cyl. 600 B.H.P. "Right Angle" gas-engine driven compressors in Commercial Solvents Corp. plant at Sterlington, Louisiana.





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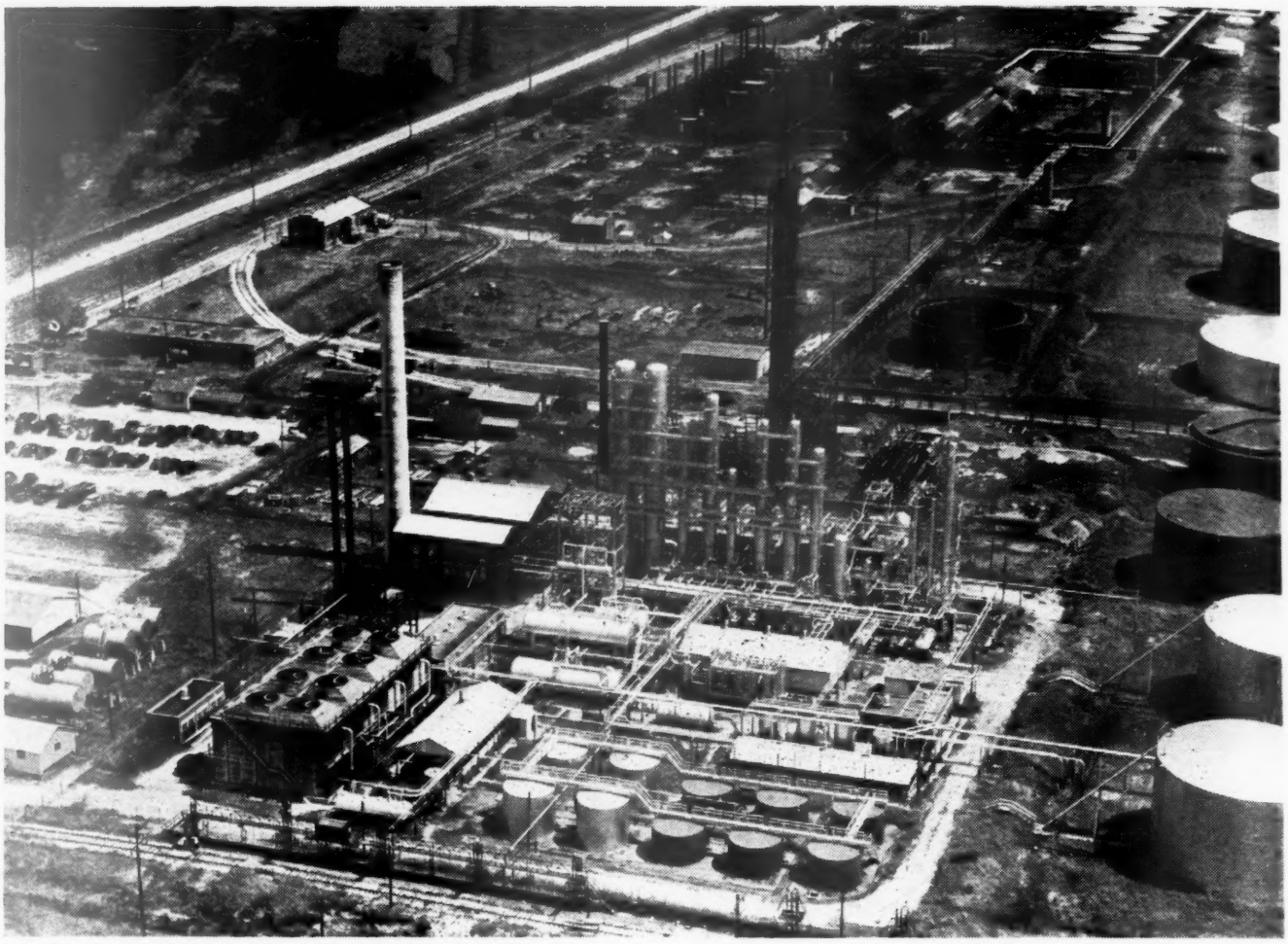

FIG. 6. Large aviation alkylation unit built by The Lummus Company in Texas.

tank gauges before the test run, because in a short test run the change of level in the tank is usually too small for accurate gauging. Except when a meter is the only possible means of measuring the flow such as a gas stream, metering is not acceptable for a test run of contract. However, it will still be useful in such cases to check the gauging as it will detect any change almost instantaneously, while by gauging, hours or even days may have passed before such change can be assured since small irregularities in gauge readings are usually assumed to be a human element in gauging.

(b) *Gauging.* Gauging is the most accurate means of measuring in a refinery. The liquid level in a tank measured by two different persons can be checked within 1/16th of an inch which is only an error of 0.026 per cent for a tank with 20 ft of liquid. For a test run of contract the gauge readings are usually checked by an outside certified gauger at the beginning and end of the run, and also in the midst of a run when a full tank is pumped down.

(c) *Sampling.* Samples can be taken from rundown tanks after the material in the tanks has been thoroughly mixed. If the material in the tank is not thoroughly mixed, then a composite sample must be made by mixing samples taken at different levels of the tank. Sometimes a composite sample can be made by mixing stream samples taken from a flowing line at regular intervals which may vary from one to eight hours, depending upon the fluctuation of the composition of the material involved. In a performance test run, a collection of stream samples is more valuable than a composite sample as the individual stream samples will indicate the effect of different variables which have been changed intentionally or accidentally during a test run. In a contract test run, however, the composite sample is more valuable as in such a case overall performance of a plant is concerned.

The proper method of sampling is just as important as an accurate laboratory analysis. This point can never be overemphasized, otherwise the control chemist will very often waste his time analyzing a non-representative sample. Sometimes the effect is worse than wasting the chemist's time, because the erroneous reports will make the operators of a plant slight the laboratory data. Very often discord has developed between the operator and the chemist, each blaming the other for not being competent. Such trouble can usually be traced to improper sampling method.

(d) *Test method.* All testing is done in accordance with the approved ASTM test methods wherever a standard procedure is applicable. Where a standard procedure has not as yet been established, the methods of conducting tests are agreed upon by the purchaser or the contractor's representative. The laboratory test data of the composite samples from a 15-day continuous test run are shown in Table 5.

● **Evaluation of data.** When all the data of the test run have been compiled, the work of calculating the yields and evaluating the performance of the plant will begin. In a 100-octane plant this can be very complicated, as mentioned in the earlier part of this paper, the 100-octane gasoline can be made by blending many different components. Let us take a particular plant for an example. A contractor guarantees to produce a certain amount of 100-octane gasoline from a reduced crude of certain specifications. The 100-octane gasoline is made by blending 91-octane straight run gasoline with isopentane from an outside source with the base stock and alkylate made in the plant. Due to the synthetic rubber program during the war, all butane and butylenes produced in the plant are delivered to a nearby synthetic rubber plant where the normal

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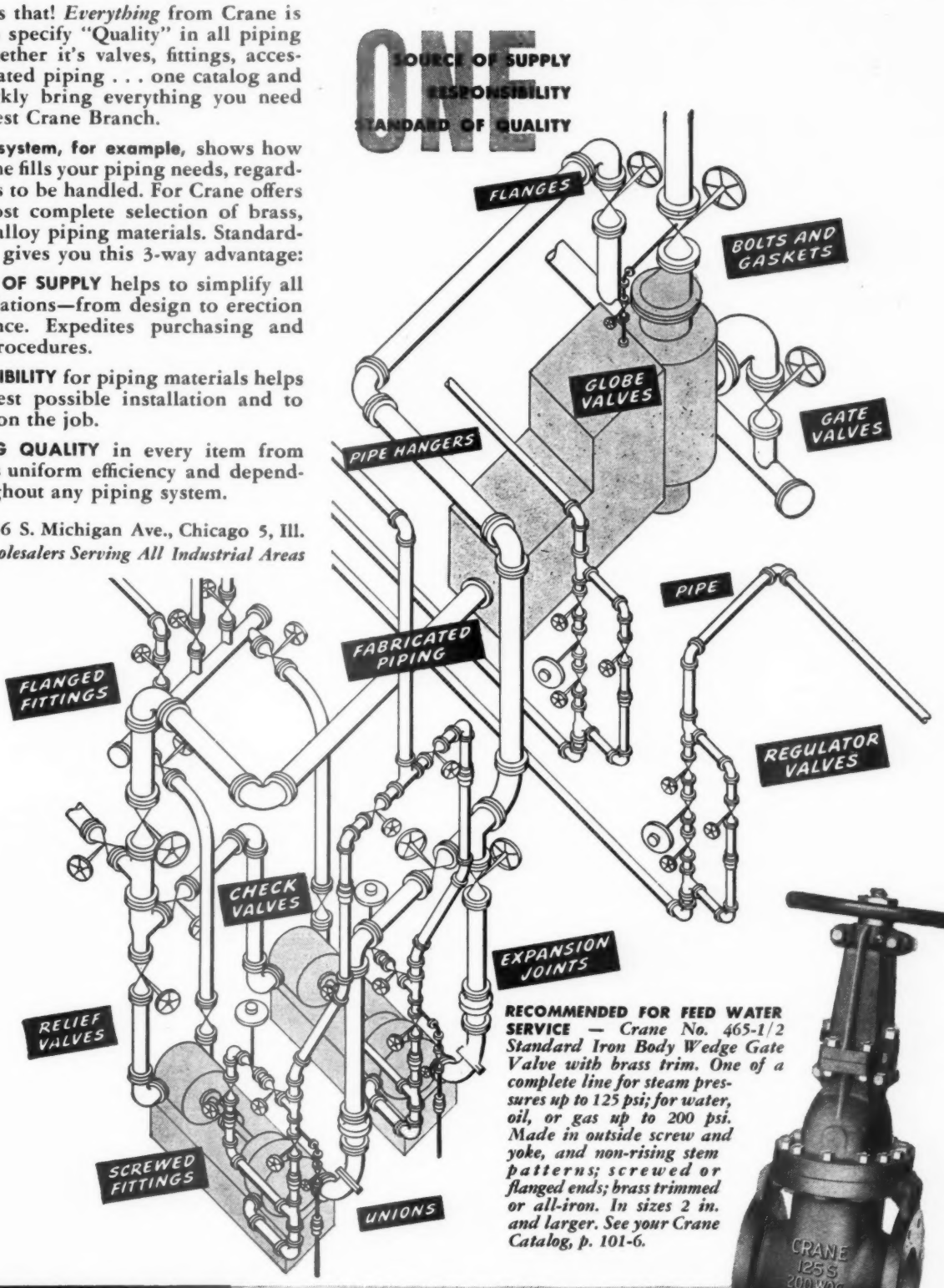

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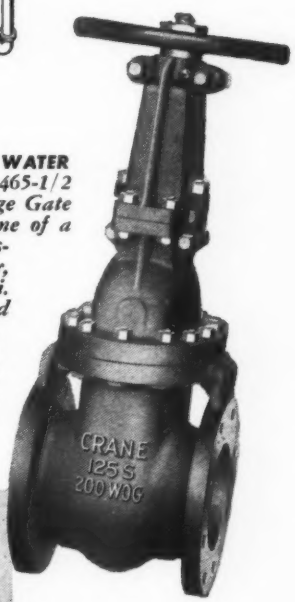

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butylene is extracted. The rubber plant returns to the gasoline plant a butane concentrate containing mostly isobutane and normal butane and a polymer of isobutylene, therefore, during the test run the butane concentrate and polymers used by the alkylation unit are made of materials delivered to the rubber plant before the test run and, also, they are mixed with butanes delivered to the rubber plant by other gasoline plants. Toward the end of the war the demand for 100-octane aviation gasoline was so urgent that all aviation gasoline plants were urged to increase their capacities to the limit. Some amylene and propylene made in the cracking unit were charged to the alkylation unit along with butylenes. Under such circumstances it is very difficult to assess an octane rating value of alkylate made under normal conditions to be used to calculate the theoretical amount of the 100-octane blend for the contract. When the plant was operated under the overloaded conditions, the octane rating of the base stock and the alkylate produced became lower. That means a smaller amount of 91-octane straight run gasoline can be added to make the 100-octane grade. Of course, the total barrels of 100-octane gasoline produced by the plant was increased. Fortunately, in this particular case, the aviation gasoline produced exceeded both in quantity and quality that specified by the contractor. Therefore, no controversial questions could be raised. The finished blend of aviation gasoline of the above case is shown in Table 7. The average operating yield data of combined catalytic cracking and treating units during the 15-day continuous test run are shown in Table 6.

● **Acknowledgment.** The author wishes to acknowledge the helpful suggestions of Mr. W. W. Kraft, Dr. E. R. Smoley, and Mr. V. O. Bowles of The Lummus Company. ★★★

TABLE 5. Laboratory inspection taken uring a 15-day continuous test run.

	Light topped crude	Virgin gas oil	Reactor charge	TCC tar	Cracker gas oil	Treater gas oil	Furnace oil
Gravity, API	26.9	34.1	28.6	17.7	17.3	12.4	28.3
Color, NPA	..	1	5+	..	Green	Green	1
B. S. and W.	0.1	..	..	..	..	..	..
Flash, °F (PM method)	..	156	..	194	154	92	208
Flash, °F (COC method)	..	..	..	320	..	..	215
Fire, °F	..	..	..	380	..	..	230
S. U. Vis at 100 F	76.0	36.0	58.0	..	..	..	36.5
Furol vis at 122 F	..	..	..	218	..	..	..
Pour, °F	..	..	..	35	..	Below 0	..
Aniline point, °F (OHD)	..	138.5	160.5	..	..	..	112.4
Diesel index	..	47.5	46.0	..	..	..	31.8
Carbon residue, per cent	..	..	0.12	..	..	..	..
Acid heat, °F	6	2	10	..	..	..	..
Distillation	Converted from 10 MM		Converted from 10 MM				
IBP	385	378	350	466	506	300	440
5 per cent	..	405	..	570	616	412	468
10 per cent	445	418	420	602	634	450	478
20 per cent	490	424	468	646	650	480	488
30 per cent	540	436	492	..	662	492	496
40 per cent	580	448	560	..	674	500	504
50 per cent	635	462	598	..	684	518	508
60 per cent	700	474	635	..	690	524	516
70 per cent	770	492	680	..	702	536	532
80 per cent	860	516	760	..	720	556	548
90 per cent	..	569	880	..	736	626	572
E. P.	..	660	896 at 91.5	..	760+	734	614
Per cent recovery	..	98.0	..	..	..	97.0	98.0
Loss	..	0.5	..	..	..	1.0	..

Note: All above tests results are the average of daily laboratory data except the vacuum distillations of the light topped crude and the reactor charge, which were made from stream samples.

	Depentanized first pass naphtha	Debutanized second pass base stock	Aviation alkylate	Heavy alkylate	Aviation blends*	
					(A)	(B)
Gravity, API	47.0	52.5	77.0	46.2	60.8	62.5
Color, Saybolt	..	30	30	1 (NPA)	30	30
Doctor	..	Neg	Neg	..	Neg	Neg
Corrosion copper dish	..	Pass	Pass	..	Pass	Pass
Octane no. motor method clear	78.5	..	..	..	..	..
F-3 octane + 4.0 TEL	..	95.6	105.5	..	100.4	100.6
F-3 octane + 4.6 TEL	..	96.6	106.4	..	101.1	101.3
F-4 octane + 4.0 TEL	..	S+1.70	S+ 1.7	..	S+1.70	S+1.70
F-4 octane + 4.6 TEL	..	S+ 2.0	S+ 2.0	..	S+2.00	S+2.00
Reid vapor pressure	1.8	3.8	9.0	..	5.8	7.0
Aniline point, °F	70.0	58.7	168	..	102.5	105.5
Sulphur, per cent	..	0.02	.001	..	0.01	0.01
Army—Gum mg	..	2.8	1.0	..	2.0	1.8
Army precipitate	..	Nil	Nil	..	Nil	Nil
Freezing point, °F	..	Below —76 F	Below —76 F	..	Below —76 F	Below —76 F
Acid heat, °F	53.5	17.5	..	..	..	..
Bromine no.	38.5	7.4	..	..	..	..
ES-45 unsaturates, per cent	30.5	5.5	..	..	..	..
ES-45 aromatics, per cent	32.5	39.5	..	..	..	..
Distillation						
IBP	150	124	92	370	108	100
5 per cent	184	156	110	382	134	120
10 per cent	198	165	118	390	144	131
20 per cent	214	181	132	396	160	148
30 per cent	234	194	145	402	180	165
40 per cent	260	214	167	408	200	186
50 per cent	288	230	202	414	216	210
60 per cent	316	247	221	422	234	228
70 per cent	342	265	227	436	244	242
80 per cent	368	279	234	460	263	260
90 per cent	386	293	246	512	285	284
E. P.	422	319	304	584	315	315
Recovery	98.0	98.0	97.0	98.0	98.0	98.0
Residual	1.0	1.0	1.0	1.0	1.0	1.0
Loss	1.0	1.0	2.0	1.0	1.0	1.0

*Aviation blend (A) contains 37.4 per cent alkylate and 62.6 per cent base stock and blend (B) 34.8 per cent alkylate, 58.2 per cent base stock, and 7.0 per cent isopentane.

TABLE 6. Test run operating and yield data for combined catalytic cracking and treating units for aviation gasoline production.

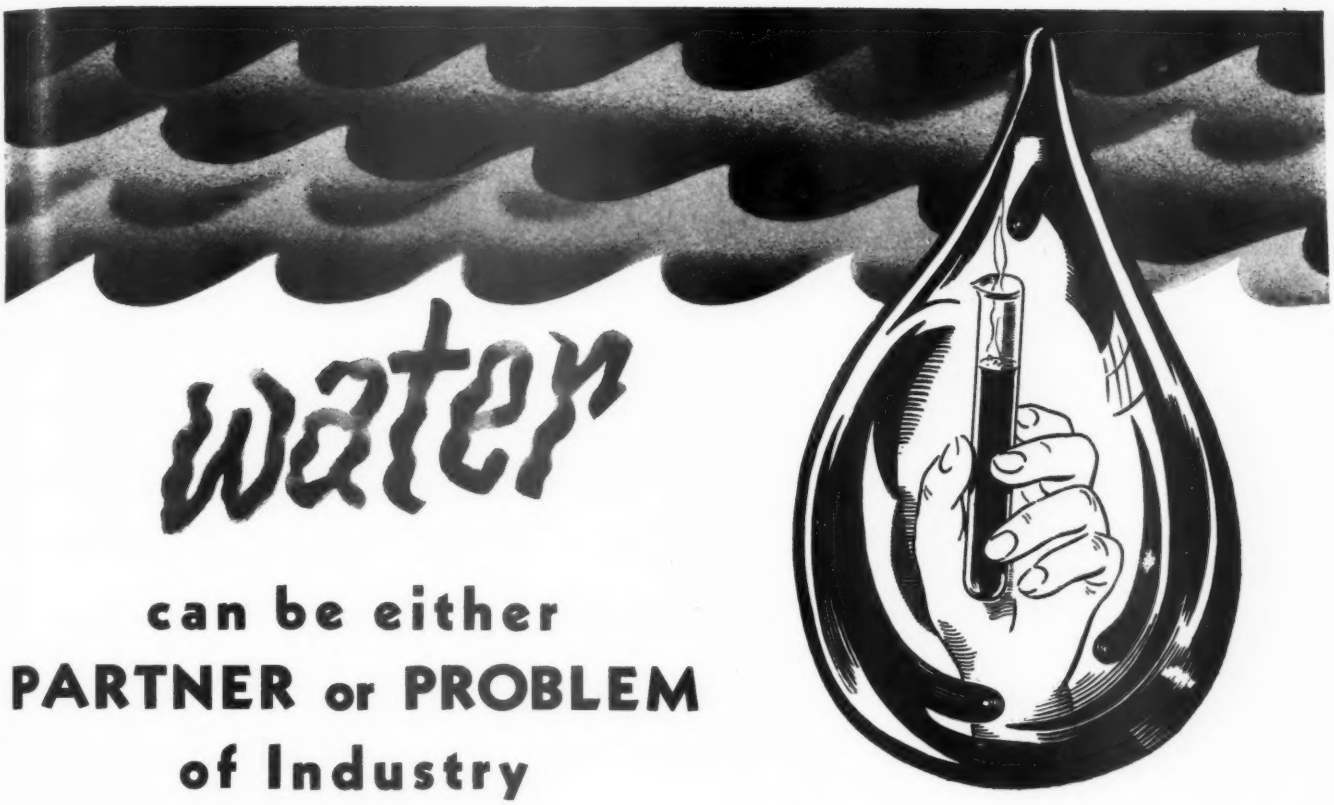
	Cracking	Treating	Combined
Operation	Once through	Total recycle	
Depth of reactor bed, ft	33	37	..
Type of reactor bed	Angle-iron	Solid	..
Catalyst	Clay	Clay	..
Oil to reactor, F	955	900	..
Oil from reactor, F	950	905	..
Catalyst to reactor, F	980	890	..
Average reactor temp., F	975	895	..
Reactor inlet pressure, psig	11.5	14.0	..
Pressure drop across bed, psig	3.8	4.7	..
Reactor charge, B/D fresh	10,191	3,764	..
Recycle	..	3,720	..
Catalyst circulation, tons/hr	100	100	..
Catalyst/oil ratio V/V	1.77	2.41	..
Space velocity V/V/H Fresh	1.83	0.22	..
Recycle	..	0.22	..
Steam with charge, wt. per cent	3.8	None	..
Coke on spent catalyst, wt. per cent	2.5	1.2	..
Coke on regenerated catalyst, wt. per cent	0.3	0.1	..
Yields on charge to unit	*Vol. %*	*Vol. %*	*Vol. %*
Depentanized 420° E.P. treating charge	36.93	..	..
Debutanized aviation gasoline	..	65.82	24.31
Cycle stock above 420° F treating charge	45.71	7.34	48.42
C_4 total	10.77	10.79	14.75
C_3 total	6.89	..	6.87
Total C^3-free liquid recovery	100.30	83.95	94.35

TABLE 7. A finished blend of aviation gasoline from a 100-octane gasoline plant.

	Actual	Prorated from actual to 10,000 B/D charge	Contract
Cracking reactor fresh charge, B/D	10,290	10,000	10,000
Aviation base stock, B/D	2,586	2,513	2,426
Aviation alkylate	1,703	1,653	1,540
Purchased isopentane, B/D	322	314	379
Finished aviation blend, B/D	4,611	4,482	4,345
AFD-1C octane with 4cc TEL	100.4	100.4	99.5
AFD-3C octane with 4cc TEL	S+1.7	S+1.7	S+1.7

To meet the Army specification of Grade 100/130 (4.6cc TEL) aviation gasoline about 13 per cent 7-lb. RVP straight run gasoline of 91 octane with 4.6cc TEL can be included in the finished blend. The composition and qualities of actual finished 100 octane delivered to the Army are listed as follows:

Aviation base stock, B/D	2586	48.7%
Aviation alkylate, B/D	1703	32.2%
Purchased isopentane, B/D	322	6.1%
Purchased 91-octane gasoline, B/D	690	13.0%
Finished grade 100/130 aviation blend, B/D	5301	100.0%
F-3 (AFC-1C) octane with 4.6cc TEL	100	
F-4 (AFC-3C) Octane with 4.6cc TEL	S+1.5 (130)	



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The first requirement for utilizing instruments is that of maintenance personnel. The instrument maintenance crew should be headed by someone with a minimum of two years' experience with measurement and control, preferably in the industry concerned. A degree in chemical, electrical, or mechanical engineering is an asset, and in many cases essential. Quite often the plant instrument engineer is also the head of the instrument maintenance department and also plant electrician. The maintenance chief should have a fair knowledge of the plant processes, a knowledge of electrical and electronic equipment and circuits, a knowledge of the principles of hydraulics as applied to fluid flow in orifices, valves, pipes, and nozzles, a good grounding in the practical aspects of pyrometry, pressure measurements, and mechanical equipment. By way of personality, he should have a reasonably even temper and sense of humor (he will certainly need both). He should be able to teach what he knows about instruments to inexperienced assistants.

The instrument men working under this head need not necessarily have previous experience with the equipment involved, but they should have a lively interest in measurement and control. They may be chosen from other plant occupations that acquaint them with the processes or manufacturing steps that are to be controlled. Care should be taken that these men are not just angling for what they consider a soft job, or possible freedom from shift work. The instrument man should be of a type who does not try to impress people with his knowledge, or to antagonize them in general. Hobbies of a certain nature are a fair indication of natural aptitude in the absence of an experience record. Thus an applicant who is a radio amateur, a model train enthusiast, or a home gadgeteer who puts strange devices on his stoker, is a good bet as an instrument trainee.

*Paper presented before Chicago Technical Societies Conference, March 24, 1948.

THE AUTHOR

H. A. Hulsberg, manager of the Instrument Department of Universal Oil Products Company, graduated in 1932 in electrical engineering from Wisconsin University. After some experience with Western Electric Company as a telephone installer, with the Temple Radio Corporation as laboratory assistant, and a short time working on waterproofing compounds, he joined Universal in 1934. Since 1936 he has been in charge of the electrical and instrument shop at the UOP Riverside laboratories. Recently he has been transferred to the Chicago office to take over direction of the Instrument Department.

By way of training, a plant school may be established, either on company time, after hours, or on a fifty-fifty basis. Instrument companies run excellent training courses to which trainees may be sent if both time and money are available. In the absence of either of these systems, the trainee may be assigned to an experienced man as helper or apprentice, until he becomes proficient enough to go on his own. During this time he should do as much as possible with his own hands, rather than just watch. All calibrations and adjustments should be checked until the trainee has proved his ability.

There are two schools of thought on the organization of a maintenance department from a personnel standpoint. One school advocates having each man a specialist in a particular type of instrument; he need know little or nothing of others. Thus, a department would consist of a pressure gauge expert, a pyrometer recorder expert, a level recorder expert, etc. The other school is that which rotates the training and experience so that each man is qualified to work on any number of types of equipment, even though less proficiently. I am inclined to favor the latter—with a strong dash of the former—to get a hybrid species that is able to work on almost anything, but has certain specialties depending upon previous experience, education, hobbies, or personal preference. With the accent upon electronically actuated recorders and controllers prevalent today, it is highly desirable to have an electronic technician to help out on maintenance and trouble shooting where other instrument men who are very good on mechanical instruments have difficulty. Electronic training is very difficult to get across in a short time.

There are also two schools of thought with regard to preventive maintenance and repair. In many cases the instrument man has so much to do that his work may consist only of rushing from one point to another to replace parts as they wear out or fail, to oil instruments when they squeak or plain stop working, and to remove dirt when it has completely fouled operation. Preventive maintenance involves a regular program of calibration checks, lubrication, cleaning, replacement of parts, and checking adjustments. Preventive maintenance may require more manpower, but the improvement in operation, and the elimination of costly shut-downs or spoilage is well worth the effort of having a definite preventive maintenance program. Morale of personnel is also improved. Emergency repairs are still a necessity, of course.

Preventive maintenance calls for a system of records. One system is to have a loose leaf notebook, each sheet of which covers one instrument, along with its serial number, plant location, and application. A number of headed columns call attention to required preventive maintenance. The dates of such maintenance, as well as of emergency repairs, are recorded, with the serviceman's initial. Sheets may be filed according to plant location, or according to instrument type or manufacture. A card index system may be preferred over a notebook system, but is not so readily portable.

Records are also important from the standpoint of training. Often a check-off system is used; this indicates instruction in particular branches of instrumentation, as well as experience in that particular branch. In larger instrument departments, various grades of instrument maintenance men may be established, dependent upon experience, aptitude, and training. Thus, grades of instrument helper, instrument mechanic, senior instrument man, etc., may be established, with varying degrees of salary and responsibility.

A small library is a help in training instrument men. A file of manufacturer's instruction pamphlets is a must for this library. Manufacturer's catalogs are very often a better way of acquainting the novice with the principles of a particular instrument than the instruction sheets by virtue of the more entertaining pictures and less ominous sounding text. "Instruments Magazine," the "Review of Scientific Instruments," and "Electronics," as well as periodicals of the manufacturing industry involved, are suggestions for current literature to be circulated or made available for home reading. Chemical, electrical, mechanical, or electronic engineering handbooks are compact sources of information for reference, as are many publications of the National Bureau of Standards.

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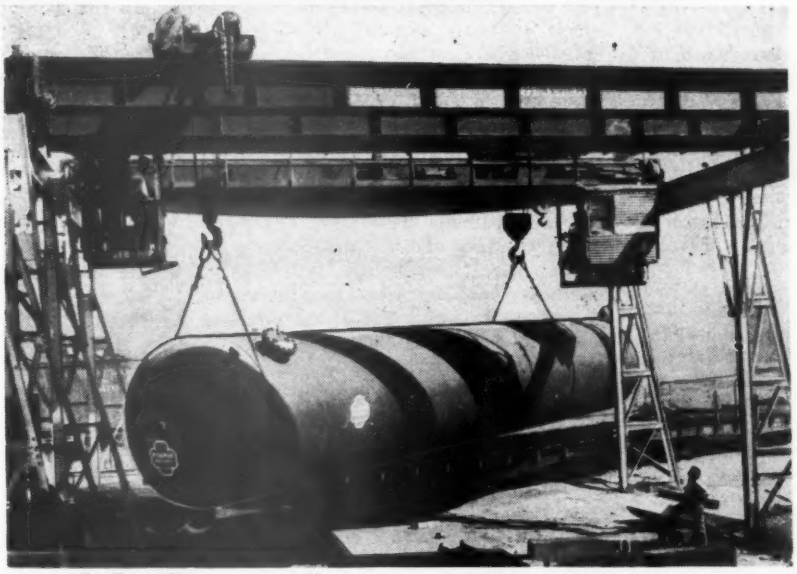

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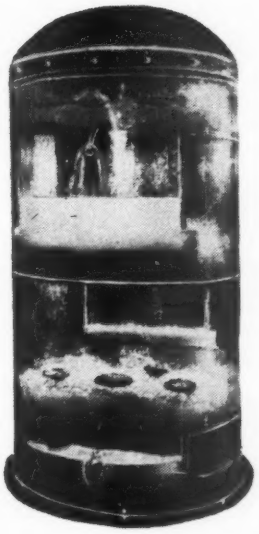

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ice center for equipment not readily serviceable in the field. Bench space need not usually be provided for every man, for most departments will have about half the help at large in the plant on service or preventive maintenance work. Space should be provided to separate clean work from dirty work. If moving coil meters must be serviced, a reasonably dust-free room should be provided. Iron dust has an annoying habit of sticking to permanent magnet fields and fouling the moving coil or galvanometer. Neatness of surroundings should be stressed, for it encourages more careful work on delicate mechanisms.

By way of tools, in addition to the usual wrenches, screwdrivers, etc., special manufacturer's tools peculiar to their particular instruments should be provided, for in many cases they save valuable time. A torch for brazing, soldering, and for welding thermocouple junctions is a necessity. Ordinary gas from the mains, plus an oxygen tank and regulator, is sufficient. Pipe and machinist's vises are required, and a portable electric drill. If a machine shop is not available, a drill press, and perhaps a small lathe are useful, particularly for control valve repairs, or for turning such items as rotameter floats.

Testing and standardizing equipment is necessary to maintain the accuracy and reliability of instruments. For thermocouple work, a portable potentiometer covering the full range of temperatures, or from zero to 60 mv, is required. If the portable does not have a variable voltage source, or "battery box" for testing moving coil meters, an external one should be provided. For work with pH instruments, a portable pH meter, buffing solutions, and another portable potentiometer reading from 0 to 1.1 or more volts should be provided, or be available in the plant. The one volt potentiometer is very useful as a standard in checking d-c ammeters, voltmeters, or standard cells. A combination Wheatstone bridge and decade resistance box is also very useful in standardizing, as well as in emergency winding of resistance coils in instruments. If electronic type instruments are used, a volt-ohm-milliammeter is a necessity, and a gas or vacuum tube tester is desirable. The latter may be eliminated if a large replacement stock of electronic tubes is available for comparison tests.

By way of pressure standards, the dead weight tester is the most reliable in the range of 15-10,000 psi. For a smaller shop, or for portable use as a secondary standard, well-calibrated, and well-kept Bourdon gauges with a hand pressure pump are satisfactory. The latter is especially useful for checking pressure recording and controlling instruments in place. For pressures in the range of 0-15 psig, a single-leg, well-type manometer is more accurate than the dead weight tester, since friction and oil viscosity tend to make the latter less reliable at these pressures. This same manometer may be used for testing vacuum Bourdon gauges, and for the higher ranges of flowmeters and differential pressure meters in general. Plant instrument air and vacuum should be available in the shop for pressure measurements and for instrument checking. In the absence of a regular plant supply, a small compressor should be provided, and a vacuum pump where vacuum measurements are made, or where evacuation of systems is required, such as for gas, vapor, or liquid filled thermal systems in conjunction with temperature instruments.

Indicating pressure gauges should be clearly labeled as to tube materials, and in many cases as to service. In food or the more exact chemical industries, serious contamination could result by interchange of gauges from one service to another. Maintenance personnel should be cautioned with regard to the danger involved in the use of oil for testing gauges used on oxygen tanks or lines, and in using the wrong Bourdon tube for chemicals such as ammonia, corrosive or volatile acids, caustics, and the like. Pressure gauges that have not been decontaminated may be a serious danger to the instrument man because of poisonous or corrosive compounds, particularly when they have become plugged at high pressures, and the compounds are released as the obstruction is removed. Indicating pressure gauges that have become hopelessly plugged or ruptured should be returned to the manufacturer for repairs, for repair or replacement of Bourdon tubes in the instrument shop is seldom economical.

For most plant work, temperature standards may be standardized thermocouples, thermometers with Bureau of Standards calibration, and for the higher temperatures, optical pyrometers. Platinum-rhodium standard couples are best at temperatures from about 600 to 2000 F. For laboratory work, melting point standards obtainable from the Bureau of Standards are convenient in calibration of couples. The ice-point, steam point, melting points of tin, lead, zinc, aluminum, and copper are commonly used. Thermocouples must be protected from contamination with calibrations of this sort, and melting metals must be protected from oxidation with carbon dust and crucibles specially constructed. Bureau of Standards bulletins covering such measurements are available. Precision potentiometers, rather than industrial, should be used for very accurate calibrations. Resistance thermometer calibrations with standardized elements are capable of very high precision and accuracy in the lower and minus temperature ranges, when used with precision potentiometers such as the White.

Water column manometers are used for calibration of differential pressure instruments such as flow and liquid level types. Single-leg well-types are much more convenient to use than simple U-tubes. Water manometers are used for differential instruments ranges up to about 50 in. of water. Above this range a mercury manometer is more convenient and portable. Inclined gauges should be used for the range of 2 in. and lower.

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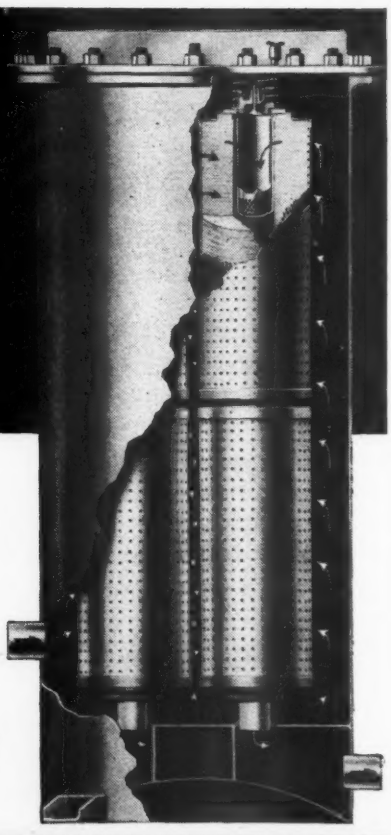

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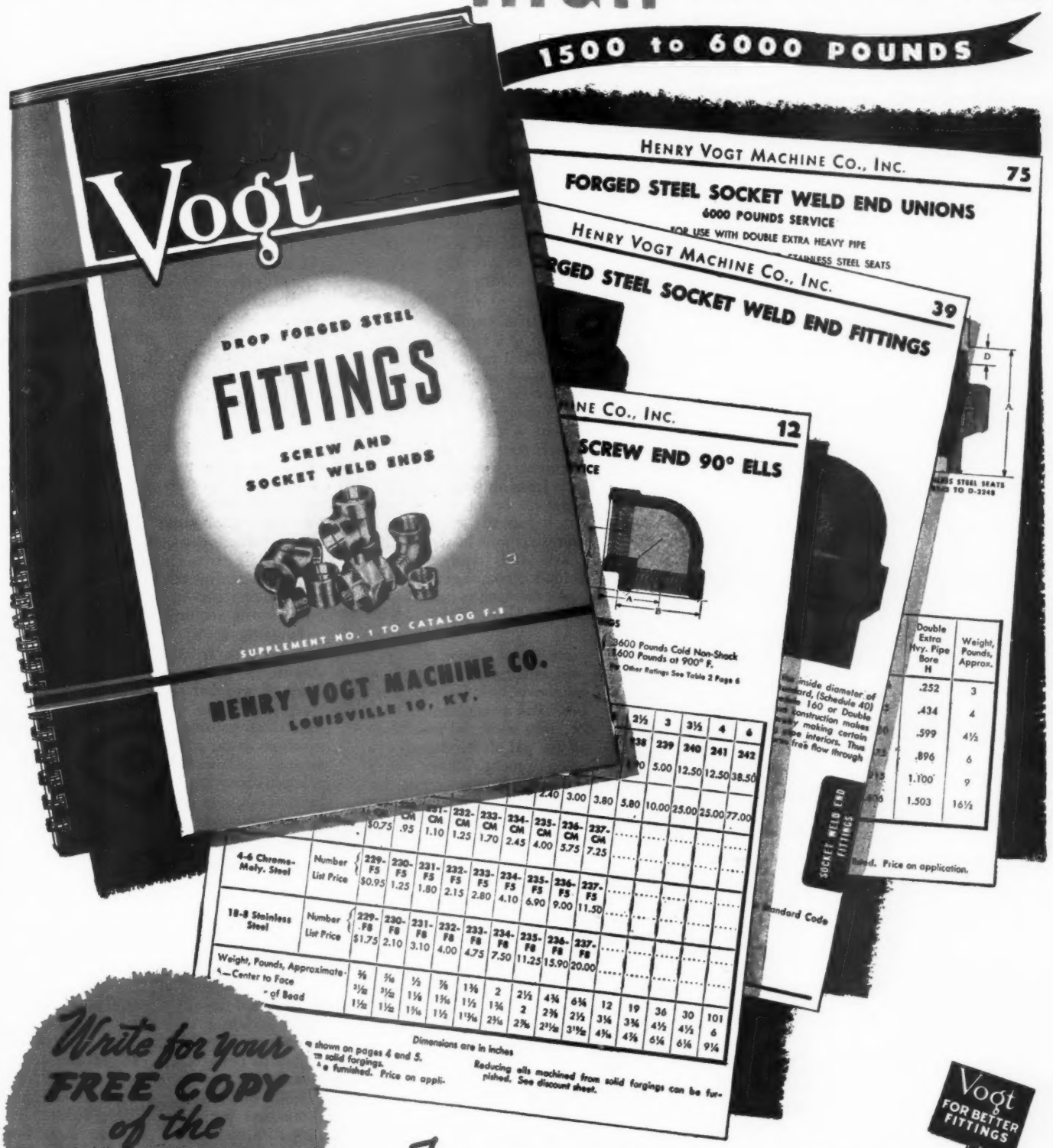
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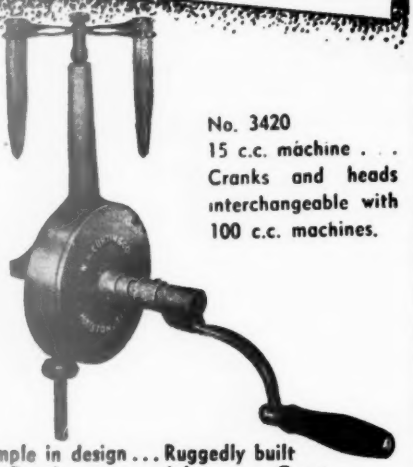

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turers of displacement gas meters. This is very convenient and accurate for gas or air flow calibrations in the range of 20 cu ft per hr to 6000 cu ft per hr. For smaller and intermediate gas flow calibrations, displacement tanks using water or oil to displace the gas are very good. For liquid flow calibrations, calibrated tanks and stop-watches are used. For all flow calibrations, good pressure regulators should be used to maintain steady flows, and temperature should be maintained as steady as is practicable. All corrections such as barometric pressure, temperature, static pressure, water content of a gas, specific gravity, and, in many cases, viscosity, should be made; or, at least, it should be made certain that such corrections are not large as compared to the accuracy required.

An essential part of the instrument shop equipment is a supply of spare parts. Upon ordering a new instrument, the manufacturer will recommend a list of spare parts, most of which consist of items of short life, or those that are easily broken. Experience with a particular instrument is the best means of finding out which parts are most likely to need replacement. Cannibalization, or borrowing parts from an instrument that does not happen to be in use is often necessary, but it has the disadvantage of making two repair jobs instead of one. Improvised parts and haywire repairs should be avoided. Prompt replacement of spares as they are used is particularly important in these days of long deliveries.

Besides spare parts, there are those that are classed as running maintenance parts, such as charts, ink for recorders, lubricants, pens and pen cleaners, mercury, thermocouple wire and insulators, and chemicals for pH electrodes and for gas analyzing equipment. Where recording is necessary to observe trends, but where the records are not filed, the permanent-type charts, where the record is washed off or erased, may be an economy.

Coordination with other departments by the instrument maintenance department is essential to successful utilization of instrumentation. If the instrument engineering department is a separate organization from the maintenance department, the purpose and specifications of new instruments should be made known to the maintenance man, and all maintenance instructions should be turned over to him. Coordination with the process engineer by the instrument engineer often can simplify the maintenance man's job by eliminating headaches. For example, the storage time in vessels under liquid level control, if properly calculated, can make instrument adjustment much more simple, as can the proper placing of valves, the allowance of the proper pressure drop across valves, the correct location of thermocouples, and the elimination of troublesome process lags. The maintenance man should report all major defects and troubles to the instrument engineer to assist him in future specifications, and to enable the instrument engineer to present his point of view.

Coordination with plant operating personnel eliminates many troubles and arguments. The instrument maintenance man should request that operators make all plant process adjustments or have the operator's sanction of any plant adjustments he may make himself. Further, an explanation of what he proposes doing will usually improve cooperation. Such a policy not only makes for better relations, but relieves the serviceman from excessive responsibility, and contributes to safety. Where disagreements on policy arise, they should be referred to those in higher authority.

The instrument man should on occasion take the manufacturer's representative on inspection trips to exchange views on servicing procedure. These trips and conferences are helpful to both parties.

Jurisdictional troubles with other workers arise frequently. A clear understanding should be had with the management of whether or not the instrument man should do certain piping, make electrical connections, do drilling or machine work, and the like. Concessions must be made where general, harmonious relations may be upset. In any case, the instrument man should be able to supervise installation work, or repair work done by other departments, to insure proper operation, whether he does the actual labor or not.

It is difficult to make generalizations on the number of instrument men required in relation to the cost of instruments, but I will hazard a few guesses. Up to about $15,000 worth of automatic control equipment requires one man, unless around-the-clock maintenance is desired, in which case three men are the minimum. Possibly the one man won't object to being called out of bed occasionally for an emergency repair. From $15,000 to $40,000 requires two men, or three men per three shifts; $40.000 to $100,000 requires three men, four for three shifts. If plant conditions are very dirty, or the atmosphere or processes conditions are extremely corrosive, these figures should be increased. Possibly for cost of instrumentation above $100,000, one man extra for each $50,000 is a fair figure.

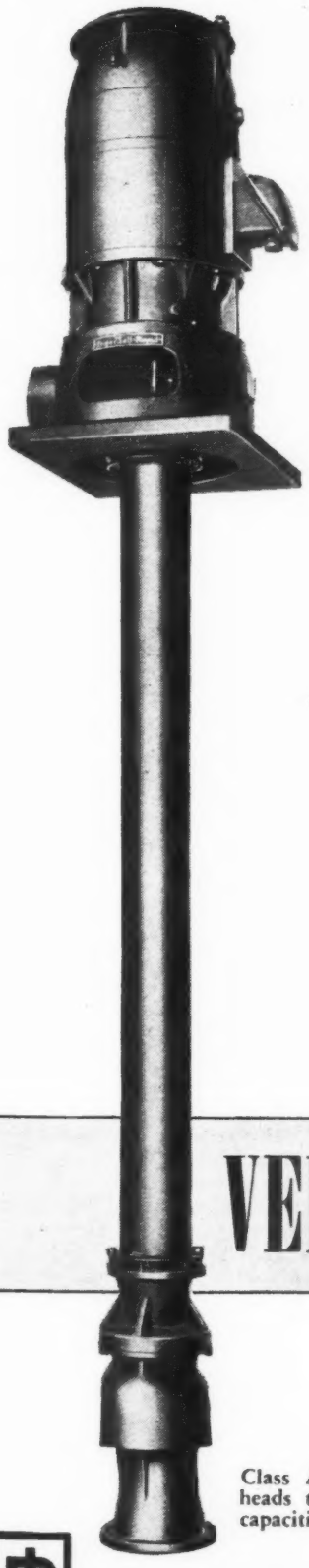
Shop area should require about 100 sq ft of floor space for each worker, including storage space, with some extra for locker and washroom facilities if these are not available elsewhere.

* * *

Well 47 years old

The Red Fork well, which began the development of oil near Tulsa, Oklahoma, was discovered 47 years ago, June 25, 1901, *The Tulsa Tribune* reports. The well flowed by heads from a depth of 548 ft and is estimated to have produced as much as 100 bbl a day. Its present rate is one barrel of oil a day on the pump, which is not so small considering the 47-year production.

One of these may answer your problem



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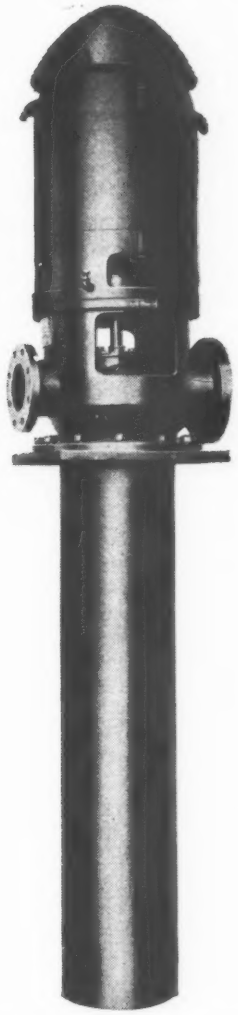

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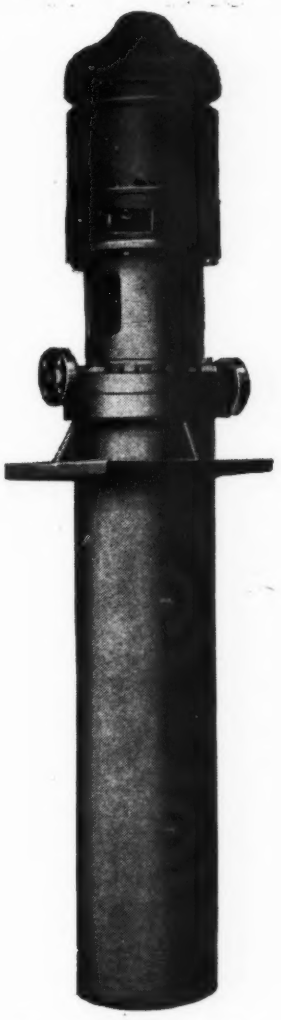

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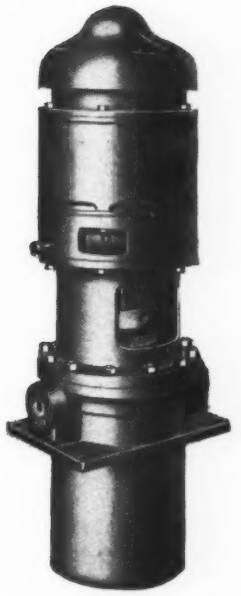

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Gasoline plant process water treatment*

By J. C. HUTCHESON, Shell Oil Company

ALTHOUGH the treatment of a particular process water once established does not vary greatly, it still is necessary to make periodic checks to see that treatment efficiency is being maintained, and that personnel are fully acquainted with treatment problems. This paper reports briefly on such a survey recently made in gasoline plants operated by a major company in the Tulsa area.

Several years ago it was the writer's privilege to set up a series of water treatments for these various plants and to instruct men, chosen by the plant superintendents, in the method of treating to be used, together with the tests necessary to control these treatments. Each plant was supplied a copy of *Water Handbook* published by W. H. and L. D. Betz, Philadelphia, Pennsylvania. This book, which has recently been reissued as *Betz Handbook of Industrial Water Conditioning*, outlined standard tests and the methods used to make them. As most of the men chosen for water treatment control were not chemists, each test was set up in such a manner that a layman could perform it. In instructing the men, the use of chemical terms was purposely avoided, in order to build up confidence. Instead, simple terms were used that were readily understandable. It has been the writer's experience that any man who can distinguish color and can add figures, can be taught to do a good job in controlling water treatment. Also, it has been found that by going into too much chemistry at first, you can cause a man to think that the process is too involved for him to handle and he does not even try. However, after a while with routine tests, most men become curious and want to know what or why they are doing certain things. Most of the men now making tests and controlling water treatments have reached that point. They all have been doing a good job and when the treatment goes wrong they have general knowledge of what to do to correct it. It was very gratifying to find this condition. Several of them have existing conditions that are beyond their control and will have to be satisfied with the water that is treated only approximately correctly. These conditions will be dealt with in the discussion of each plant. Some of these conditions may be corrected, whereas to correct others may not be economically sound. It will, therefore, be necessary to decide what can be afforded, as some plants will be able to spend more for good water that others.

*Presented before Natural Gasoline Association of America December 12, 1947, Panhandle Plains Regional Meeting, Amarillo, Texas.

It was a pleasure to note that several of the men have become so interested that they have purchased chemistry books to study further the art of water treatment. Unfortunately, most chemistry books do not cover water treatment specifically and it takes a lot of reading and studying of other subjects to get what is finally required. It is suggested that these men be given a book entitled *Boiler Feed and Boiler Water Softening.* (Boiler Operators' Manual by H. K. Blanning and A. D. Rich, published by Nickerson and Collins Company, Chicago). This manual gives in a condensed form a practical treatise on how to determine the cause of boiler scale and how to maintain clean heating surfaces, together with instructions for testing and treatment. This book would satisfy both the engineer and the layman and will be very beneficial to the men who use it.

In general water treatment, as it is known in these plants, consists of either lime and soda ash (Cold Process) batch treatment, or a Zeolite treatment, or no treatment at all as far as raw water is concerned. In two plants lime and soda ash treatment is used as the original treatment. This is followed by an after-treatment of phosphate in combination with tannin in boiler and cooling water. One of these plants has continuous blowdowns on the cooling water system, while both have continuous blowdowns on the boilers, and use algaecide treatment to keep down algae and slime.

It should be recognized that in the lime and soda ash treatment the hardness of the water together with suspended matter is precipitated as sludge thereby reducing the total solids in the water to be used in the various systems.

In two other plants a Zeolite water softener is used as initial treatment of the raw water, which in both cases is followed by phosphate and tannin in the boilers. One uses acid treatment in cooling water and the other uses Scale X as a treatment, and both plants use algaecide for the control of algae and slime.

It has been the writer's experience in controlling algae that regardless of what type of algaecide is used, in time the vegetable growth will become immune to that chemical. It is then necessary to use another algaecide for a period of time, after which the original may again be used. Inasmuch as copper sulphate is one of the cheapest algaecides that can be purchased, it is most generally used. When algae becomes immune to copper sulphate, the plants have been using Santobrite, until such time as copper sulphate again becomes effective. The use of any algaecide should begin before too much algae is present or it may result in the killing of a large amount of algae, which will float in the water through the system and probably clog up some of the water passages, causing extensive shut downs and expensive cleanout jobs. If this treatment is not begun early, a small amount of chemical should be used at first so that all algae will not be killed at one time. The treatment can be gradually increased until finally all algae is destroyed.

Secondary treatment of cooling water can be handled in one of two ways: (1) Either convert to sulphate the carbonate that is formed by the liberation of CO_2 from the bicarbonate radical, or (2) hold the carbonate in solution. In the latter case the calcium carbonate must either be held in solution by chemical means or controlled by continuous blowdowns so that the concentration, due to evaporation of water, windage loss, etc., in the tower, will not build up to a point where the calcium will precipitate. Calcium carbonate precipitation forms a hard scale on the metal thereby reducing the heat transfer in the cooling system. The solubility of this compound is very low being approximately 92 ppm at 32 F, about 15 ppm at 212 F, and about 10 ppm at 356 F.

When conversion of the carbonate radical is employed, this is generally accomplished by the use of relatively cheap sulphuric acid. By the use of this acid, the calcium bicarbonate is converted to the more stable and soluble calcium sulphate. At the temperatures normally encountered in cooling water, we can safely carry 1200 to 1600 ppm of calcium sulphate without serious precipitation. This also allows us to increase the concentrations of total solids that may be maintained in our cooling systems.

A comparison between untreated and treated cooling water is given by Betz, as follows:

	Raw	Untreated	Acid-treated
Total hardness as $CaCO_3$	75	135	510
Sulphate as SO_4	20	60	1265
Alkalinity to methyl orange as $CaCO_3$	200	600	250
Calcium as $CaCO_3$	50	65	340
Magnesium as $CaCO_3$	25	65	170
Blowdown gpm		57	7
Makeup gpm		225	175
Cycles of concentrations		3	7

With 50 ppm of calcium present in the raw water and three cycles of concentration, the circulating water should have contained 150 ppm if none had precipitated to form scale or sludge. Actually, 65 ppm of calcium is present which means 85 ppm has precipitated as scale.

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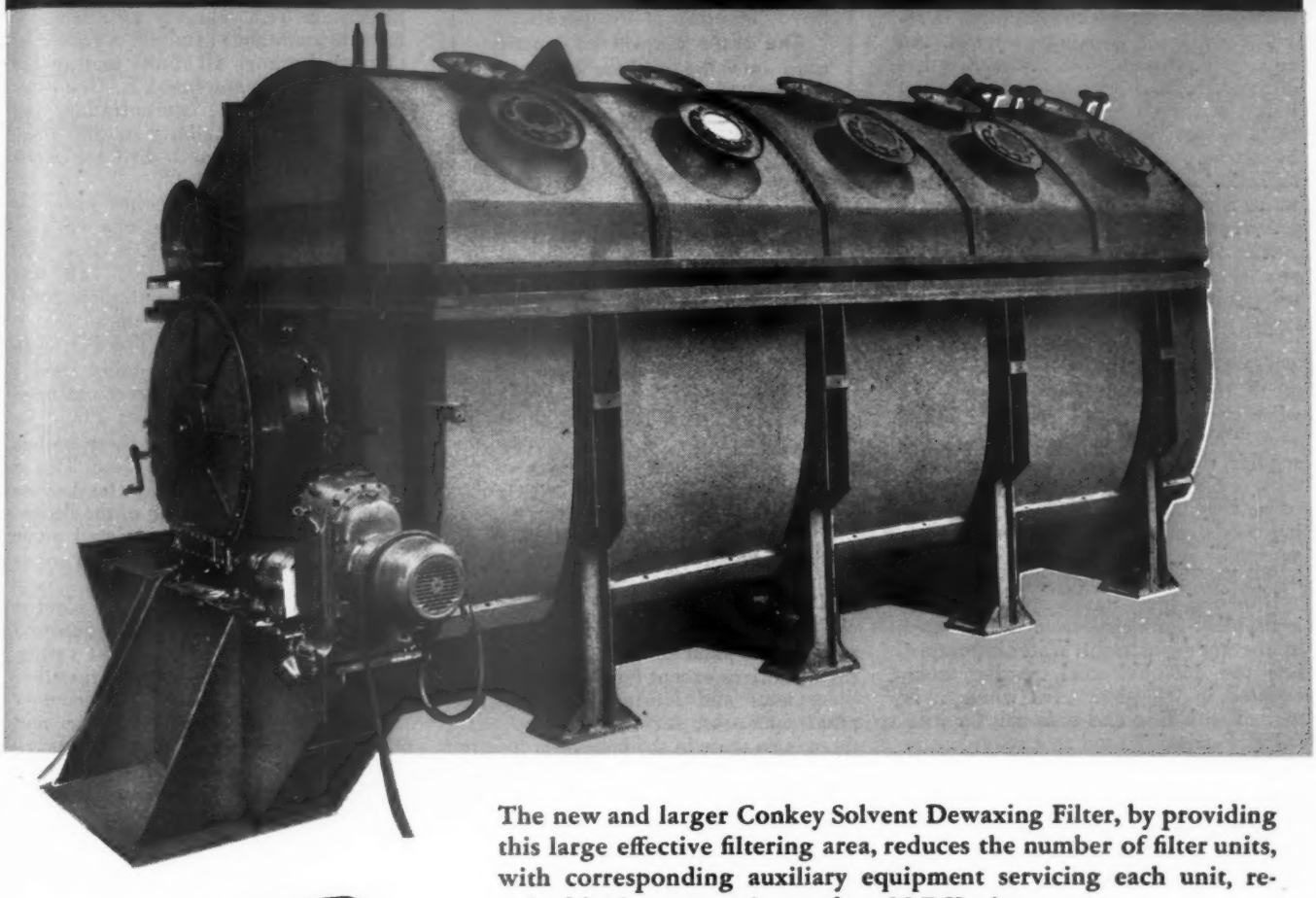

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With the acid treated water, it can be seen by comparison, that the methyl orange alkalinity has been limited to 250 ppm whereas the sulphate content of the water has been sharply increased to 1265 ppm. With 50 ppm of calcium in the raw water, 350 ppm would be expected in the water having seven concentrations. Actually, it was found that 340 ppm of calcium was present, which represents 97 per cent maintained in a soluble form. One big advantage of the acid treated water, therefore, was the retention in solution of scale forming material. An equally important point, however, is that 50 gpm, or 22.2 per cent less make up water was required due to the reduction in blowdown losses made possible by carrying higher concentrations of total solids. In many gasoline plants where water is a scarce item, this assumes major proportions.

All boilers in the plants have continuous blowdowns and most of them are using phosphate and tannin as an internal treatment to condition sludge and to correct for caustic embrittlement. These boilers are being operated from 30 to 160 days without cleaning out whereas before internal treatment they were cleaned out every 30 days, as a regular routine. Some of these boilers now, even after 160 days' operation, cause very little trouble so far as cleaning out is concerned. More time is consumed in cooling off and bringing the boiler back to pressure than in cleaning.

In one of the plants inspected, water is supplied from shallow wells operated by another department. Water is pumped into two 1600-bbl steel treating tanks situated in the plant yard where it is treated with lime and soda ash for softening. Ferrisul is used as a coagulent to weight down and hasten settling of the fine precipitant formed by the lime and soda ash.

The chemicals are mixed with water in a steel container, thoroughly agitated and transferred to the full settling tank by means of a steam injector. Water in the settling tank and the chemical charge are then mixed by air agitation after which the treated water is allowed to settle for a minimum of 8 hr. It is then drawn off by means of a swing pipe, which allows the top water in the tank to be drawn first and discharged into the engine jacket hot well situated at the southwest corner of the compressor building. From here it is pumped through the engine jackets and to the bottom ring of a 55,000-bbl steel tank south of the plant yard. A portion of the treated water is pumped to the hot well serving the boiler plant. The cooling water make-up is from the engine jacket system.

This is not an ideal condition for several reasons. In the first place, the treatment of water is what is called the batch treatment, that is, a quantity of water is treated, settled, and then added to the system all at one time. This water is then circulated until the next batch is ready, which is a minimum time of 8 hr. One of the worst features of this practice is the fact that treated water is dumped into an open-top concrete pit that is level wih the ground elevation.

Oil shale shipped

A railroad tank car of more than 6000 gal of crude shale oil —the first bulk shipment of oil from the Bureau of Mines' new oil shale demonstration plant near Rifle, Colo.—is undergoing preliminary tests in the laboratories of a private oil company at Riverside, Illinois, according to James Boyd, Director of the Bureau.

The shale oil will be fractionated into the various grades of crude oil by the Universal Oil Products Company, after which the Union Oil Company will conduct cracking and other refining studies.

Dirt and weeds naturally get into this pit. Several years ago approximately 18 in. of mud were removed from this pit and now approximately 14 in. more have accumulated. Even though the suction of the circulating pump is screened, considerable mud goes through the system and into the large steel tank, which has several feet of mud in it. Some time ago an attempt was made to clean this out but when the mud was removed, the tank bottom began to leak so badly that rather than to go the expense of repairing the tank the effort was abandoned. Considerable mud gets from the hot well into the boilers requiring that they be shut down approximately every 30 days to clean the mud off the crown sheet. Tests made at the plant show excellent operating conditions except for this mud. From these tests and information from the plant operators, it was indicated that there is no scale in the boilers. If it were possible to eliminate the mud from the boiler make-up water, the writer is of the opinion that instead of 30 days, these boilers could be operated 60 to 120 days without clean outs.

The boiler feed hot well is a horizontal tank set on a pipe frame. It was suggested that a 4-in. collar be welded into one end of this tank with the bottom of the collar approximately 4 in. off the bottom of the tank. A 4-in. pipe would be placed inside the tank and 41 $\frac{5}{8}$-in. holes drilled on 6-in. centers throughout the length of the pipe. The holes would be staggered on a 45-deg angle from the center line of the pipe, installed looking down, and a quick opening valve placed on the outside of the tank and connected to the sewer. This valve would be operated as often as necessary to keep the mud in the hot well to a minimum. It is recognized that this will be a makeshift method, but it may reduce the mud going to the boilers so they can operate for a longer period, thus saving shutdown time, and freeing for other plants operations labor now used to clean out the boilers.

Another of the plants showed excellent results. The concentration in the cooling water, the engine jacket, stabilizers, and distillation unit were 3 to 8.6. The methyl orange alkalinity is 152, 350, and 470 ppm, respectively. Higher concentrations should be carried if acid treatment were used on this water, thereby reducing blowdown and consequent make-up water. This would also lower methyl orange alkalinity and minimize scaling tendencies now present.

The water in all the boilers, except two, was in excellent condition. No. 5 boiler had just been put on the line after having been stored full of undiluted make-up water for 21 days. The methyl orange alkalinity of the water in this boiler was 1016 ppm, and the concentrations were 17.3, whereas an attempt is made to maintain a maximum of 500 ppm of methyl orange alkalinity and around 250 ppm of phenolphthalein. One other boiler had only 3.3 concentrations and methyl orange alkalinity of 280 ppm, which indicated that it had too much blowdown.

In a third plant the boiler water, so far as methyl orange alkalinity was concerned, was pretty much in line with the exception of one boiler. This was found to have a stopped continuous blowdown, which was opened up so that it would function properly. The PO_4 radical was somewhat low ranging from 5 to 20 ppm in place of the recommended 35 to 60 ppm phosphate as PO_4. The chloride concentrations of these boilers were being maintained at 4 to 5. This is necessary because of the high total solids due to the raw water being of the Zeolite treated type in which the treated water actually has an increase of total solids over the raw water.

The cooling water in another plant is treated with sulphuric acid. The methyl orange alkalinity in the jacket system was found to be 146 ppm and in the other system 240 ppm. The chloride content was 240 ppm in the jacket system and 680 ppm in the other. The methyl orange alkalinity in the water from the Zeolite softener, which is used as make-up water for these two systems, was found to be 300 ppm whereas the chloride was 120 ppm. This means that the jacket water has two concentrations whereas the other water has 5.65. The methyl orange alkalinity of both systems was well within the range of 250 ppm.

The boilers at this plant had a methyl orange alkalinity of 612 to 910 ppm. The phenolphthalein alkalinity was from 512 to 790 ppm. The phosphate as PO_4 was 5 to 15 ppm. The writer feels that this phosphate radical should be higher, but the operators at this plant say that there is very little scale in the boilers, no pitting, and they are able to operate from 160 to 190 days without shutting down, which certainly is good service.

At another of the plants no treatment is used except internal water treatment for the boilers and algaecide for cooling water. Tests on the first day indicated that the methyl orange and phenolphthalein alkalinities of these boilers were extremely high whereas the phosphate was 25 to 45 ppm. Two days of excessive bottom blowdown reduced these alkalinities but not sufficiently to be satisfactory. Instructions were left with the operators to continue bottom blowdown until the alkalinities were reduced to a methyl orange alkalinity of approximately 500 ppm in each boiler. The coil pit at this

plant showed very little algae and scale, these being controlled with copper sulphate augmented with Santobrite, and blowdown, when necessary.

The pH value of the cooling water in the 85-hp Climax engine was found to be 8.8. This engine is cooled with distilled water, treated with soda ash to produce a minimum pH of 8.5, after which sodium dichromate in the amount of 500 ppm is added. This imparts a dark yellow color to the water. A sample of water from the engine was found to be light yellow in color, which indicated a deficiency of sodium dichromate. It was recommended that additional chemical be added.

Tests on the 145-hp Climax showed the pH to be 9.0. The color for sodium dichromate seemed to be all right; however, there was quite a sludge in the sample bottle. Suggestions were made to drain and flush this system and recharge with treated water.

Water supplied the last plant visited is pumped from a lake to the engine jacket and boiler system without treatment. Boiler water is internally treated with soda ash and sodium aluminate. The methyl orange alkalinity in the boilers on the first day was 436 to 1028 ppm. The phenolphthalein alkalinity was from 352 to 808 ppm. By excessive bottom blowdown, the methyl orange alkalinity in boiler No. 1 was reduced from 1028 to 836 ppm.

Alkalinity in boilers Nos. 2 and 3 increased during this time, probably due to the large amount of insufficiently treated raw water added to the system to compensate for the excessive blowdowns. All three boilers were then blowndown excessively by bottom blowdown the next day, resulting in a methyl orange alkalinity of 152 to 220 ppm, which was too low. Instructions were left to reduce bottom blowdown, depending on the continuous blowdown, until the methyl orange alkalinities reach 500 ppm.

Copper sulphate is the algaecide normally used in the coil pit at this plant. Some immunity had been built up to this material and the use of a different chemical was desired by the superintendent. As the operators must enter the coil pit at frequent intervals to make repairs, the temporary use of copper chloride was suggested.

Naturally, it will be recognized that the foregoing deals not with the latest water treating methods and water plant system design, but is rather an attempt to show what can be done to improve operating conditions in plants using older treating equipment along with the various chemicals now available. This, however, is an important phase of plant operation where capital expenditures are out of the question and operating costs must be held to a minimum.

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Automatic controls in gas operations*

By L. W. PARTEN, The Foxboro Company

AUTOMATIC control is playing an ever-increasing part throughout industry. As process problems increase so do those of the control engineer. Many users of automatic controllers have only a hazy notion of how they operate, because the operation of the controllers is an incidental part of their work. Better knowledge of automatic controllers will be of considerable help to them, however, as well as to those responsible for the maintenance of the controllers. The purpose of this paper, therefore, is to present briefly, and in simple terms, the theory of the present-day controller, together with the means by which this theory is translated into practice.

The pneumatic controller is a device equipped with a measuring element capable of detecting changes in the variable to be controlled and translating these changes into movements of a valve capable of influencing the controlled variable.

Automatic control for the gas industry can be classified under four main types: "On-off," "floating," "proportional," and "proportional with reset." As the floating types usually have an inherent throttling range, they can be grouped with the proportional controllers.

The different types of control action produced by these three controllers are illustrated by a series of curves that has been prepared in which the motion of a measurement and the resultant motion of the valve are plotted. It is particularly important to understand that the valve action, plotted as the lower curves, is not influencing the measurement, which is the upper curve. Such a series of curves could be produced physically moving the measuring pen in a controller and recording the resultant changes in output air pressure while the instrument is disconnected from the valve. The purpose of the curves is to show what the control mechanism is designed to do, rather than to show the result of this action when it influences the measurement.

● **On-off control.** Fig. 1 illustrates the valve action of an on-off controller whose measurement is responding to the changes shown. It may be seen that a valve action occurs only as the measurement crosses the control point and that the valve then operates from one extreme to the other. For all positions of the measurement above the control point, the valve has one position, and, for all positions below the control point, the valve has another position.

It follows, therefore, that the measurement of an on-off controller must be continually cycling when it is in operation; otherwise, the valve would remain at either the open or the closed position. When applied to processes suited to this type of control, the amplitudes of the cycles are so small that the record may be considered a straight line. This type of control is satisfactory, therefore, in many applications such as the temperature control of a large mass by the periodic admission or removal of heat.

A common illustration of this type of control is the thermostat in an ordinary home, which measures the temperature in the room and, if the measurement is low, turns on the furnace and keeps it running until the measurement has reached the control point, at which time the furnace is shut off again. When the measurement again drops below the control point, the furnace is turned on, and so the cycle continues.

● **Proportional control.** In the following discussion of the motions and changes in output pressure of a controller, it will be assumed that the output pressure of the controller is at all times within the limits of 0 to 17 psi. It is always possible to move the measurement so much that the air pressure reaches one of these limits. This means, however, that the controller has gone out of its working range, and consequently, the relationship between air pressure and measurement motion that has been established need no longer remain as stated.

A proportional controller whose meas-

*Presented before the second annual Gas Technology Short Course, Texas College of Arts and Industries, Kingsville, Texas, May 27-30, 1947.

FIG. 1. "On-off" valve action diagram.

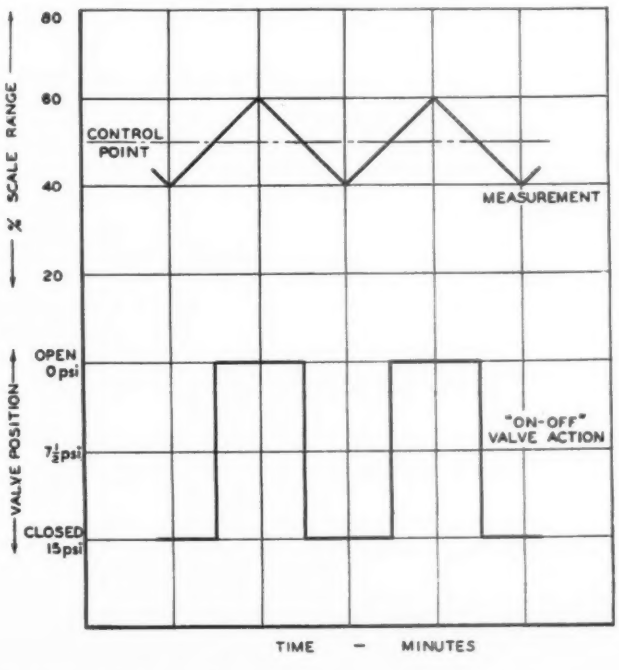
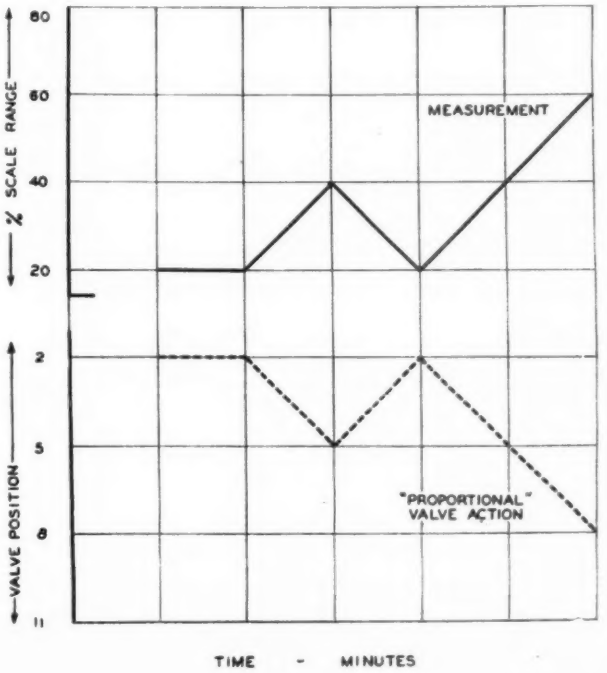


FIG. 2. "Proportional" valve action diagram.



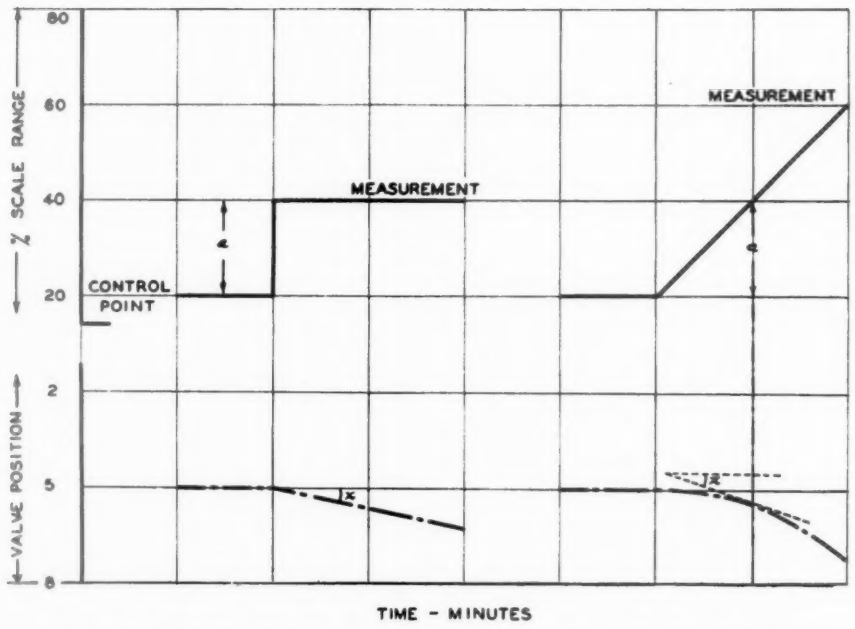


FIG. 3. "Reset" valve action with fixed deviation.

FIG. 4. "Reset" valve action with increasing deviation.

urement is moving at a constant rate produces a valve action such as that shown in Fig. 2. The difference between this and the on-off controller is apparent at once as, in the latter case, the valve moves intermittently, whereas, in the present case, the valve continues to move so long as the measurement is moving, assuming that the valve does not reach the limit of its stroke. At any time the amount of valve movement is directly proportional to the amount of measurement movement, and it is in a direction to oppose the motion of the measurement. The valve position always bears a fixed relationship to the measurement, and the peak value in valve motion occurs at the point of greatest mesaurement deviation.

In the usual proportional controller, it is possible to vary the amount the valve will be moved by a given measurement change by adjusting the proportional band of the instrument. The proportional band of a controller is defined as being the percentage of the scale through which the measurement must move in order to produce a travel of the valve from one extreme to the other. Thus, a 100 per cent proportional band controller is one where 100 per cent scale movement of the measurement is required to give 100 per cent valve movement.

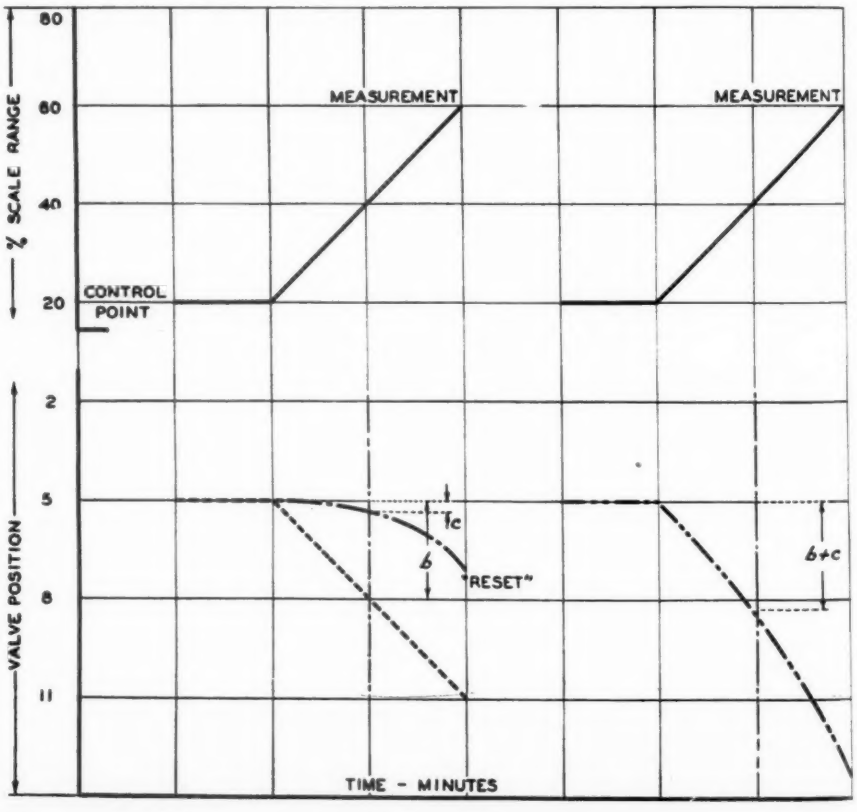
It is important to understand that each valve position of a proportional controller is related to a definite position of the measurement. The controller may be adjusted so that the valve is positioned to bring the measurement to the desired value, but the measurement will be maintained at this point only so long as there is no change in load or other variables. If, for example, the pressure drop across the valve changes, then it must assume a new position in order to pass the original flow. Therefore, the measurement must first move to a new position that necessarily will be away from the control point. This drift from control point with load or condition change is known as "off-set.' It may or may not be objectionable depending upon its magnitude and process requirements. It follows logically that the off-set on normal changes in load will be small when the proportional band of the controller is narrow, whereas it will be correspondingly larger, when the proportional band is wide.

● **Proportional with Reset control.** When operating conditions and the proportional band of the controller are such that the maximum off-set is within the permissible variations of the controlled medium the proportional controller is satisfactory. When conditions are not satisfied, however, it becomes necessary to add a second function to the controller to overcome these objections. This function is known as "reset." Fig. 3 illustrates the pure reset action for a sustained measurement deviation, showing that, whereas the measurement is deviated a given amount, the valve continues to move at a constant rate. Fig. 4, on the other hand, shows the reset action on an increasing measurement deviation, emphasizing that the rate of reset is increased as the deviation becomes greater. The fixed deviation "a" (Fig. 3) has produced a correction rate that is measured by the fixed angle "x" in Fig. 4, however, that rate of correction increases as the deviation increases and reaches a rate "x" determined by the angle between the tangent to the curve and the horizontal when the deviation reaches the value of "a."

By combining the proportional and reset functions in a single controller, the valve action for an increasing deviation will be the sum of the curves, Figs. 2 and 4. As shown in Fig. 5. The important point in Fig 5 is the fact that there are two distinct reactions produced by a given

FIG. 5. "Proportional and Reset" valve actions (separated).

FIG. 6. "Proportional and Reset" valve action (combined).



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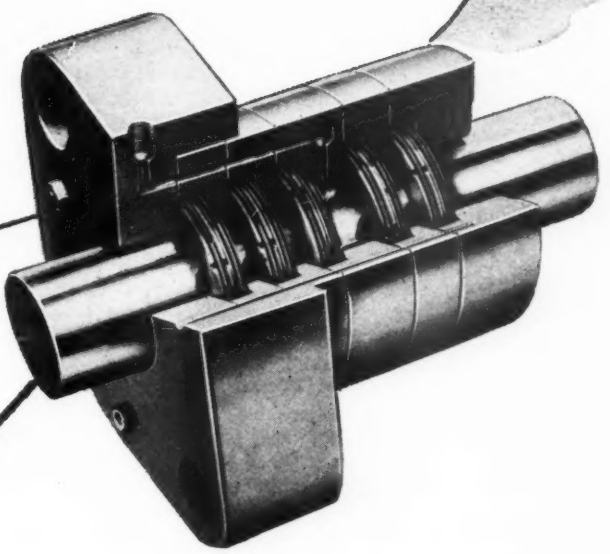

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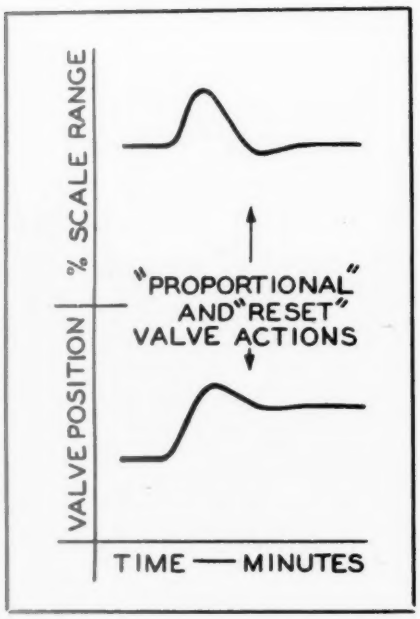


FIG. 7. Recovery curves for "proportional" and "reset" valve actions.

measurement change. The amount of corrective action due to the proportional action will increase only as the magnitude of deviation increases, whereas the amount of corrective action due to reset will increase as the magnitude and duration of deviation is increased. In other words, one correction is governed primarily by the duration of deviation. Fig. 6 shows the combined result of the two curves in Fig. 5. This is the action that will be obtained by use of a proportional and reset controller.

Fig. 7 illustrates the motion of a measurement together with the motion of the valve. Unlike the previous curves, however, the measurement is being controlled by the valve. The initial movement of the measurement was caused by a sudden and sustained load change of considerable magnitude. The valve reacted to restore the measurement to the original control point, and it may be seen that the measurement was returned to the control point with a minimum of cycling.

It should be noticed also that the valve had assumed a new position when the measurement was returned to the control point. The original motion of the valve responding to the motion of the measurement was due to proportional action. The departure of the valve to its new position, however, was due entirely to reset. Had the controller been a simple proportional type where the position of the valve is related directly to the position of the measurement, the load change would still have called for a new valve position, but this could have been obtained only with a sustained deviation of the measurement. The system would therefore have been stabilized with both measurement and valve in new positions, unlike the reset controller that will place the valve in a new position with the measurement still at the control point.

The foregoing discussion has established the action that may be expected from the three types of pneumatic controllers. We should now re-examine these actions to determine just how the pneumatic equipment produces them.

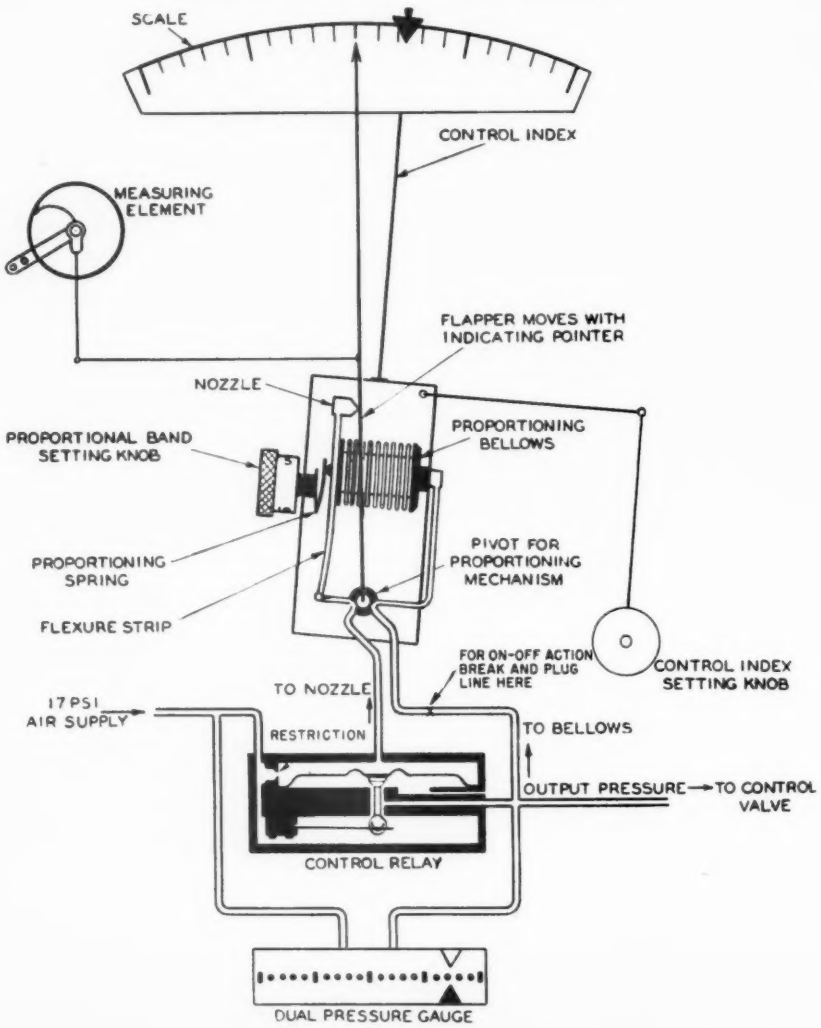
● **On-off control mechanism.** Fig. 8 shows such a controller. The proportioning bellows are disconnected as indicated for on-off action, so that no feedback will occur. For the action shown in the diagram, when the flapper covers the nozzle, pressure is built up above the diaphragm of the control relay. This causes it to move so as to cut off the vent and put the full 17 psi air supply on the control valve. When the flapper leaves the nozzle, air is bled from above the diaphragm of the control relay, which then moves in the opposite direction, cutting off the supply and opening the vent so that pressure on the control valve drops to zero. Opposite control action is obtained simply by moving a lever. Note that aside from the very small amount of throttling inherent in the flapper-nozzle system (less than 1/10 of 1 per cent), only two positions of the control valve are possible. It is either open or shut.

Although the on-off controller is not used to any extent in the natural gas industry, special adaptations of on-off action are of considerable interest. One such case is the differential limit controller, which is used for automatically cutting in a second meter run when the capacity of the first is reached.

Fig. 9 is a sketch showing a differential limit controller installation of the recording type in which the limit mechanism is added to a standard flow recorder. The on-off control valve in the secondary line is positioned by the differential limit control mechanism, which is operated by the primary line differential.

The mechanism for this type of controller is shown in Fig. 10. The nozzle positions are set by the high and low indexes at the differentials at which it is desired to have the secondary meter run cut in and out. For a 100 in. range meter, this could be at 98 in. and 10 in. These settings are easily changed, however, by external setting knobs. The index pointer, or pen arm for the recording type, is actuated by the meter bearing shaft and carries the striker arm that lifts the flappers from their corresponding nozzle when the pointer is below the corresponding index setting. The striker arm permits the flappers to cover these nozzles when the pointer is above the corresponding index setting.

FIG. 8. "On-off" control valve mechanism.



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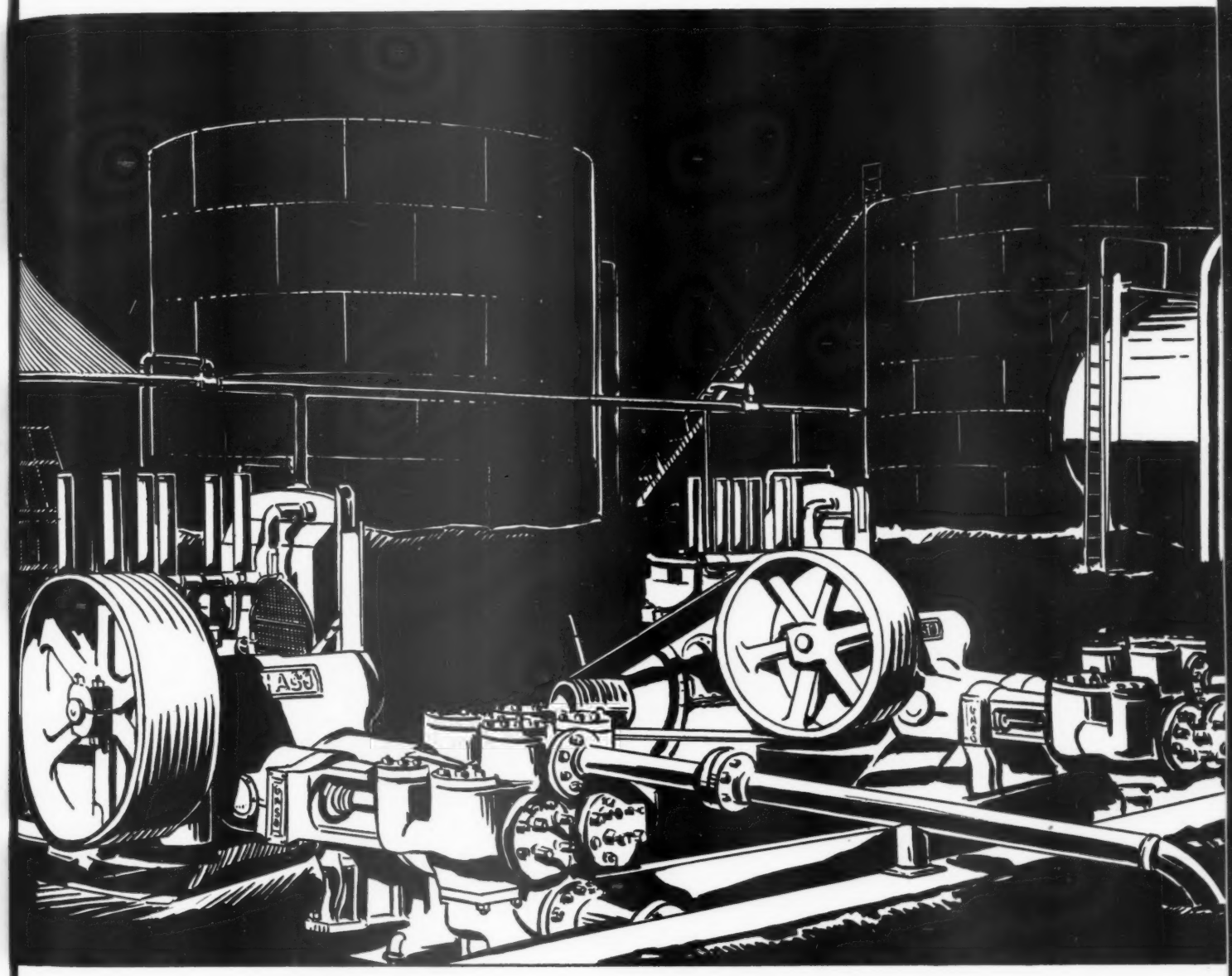

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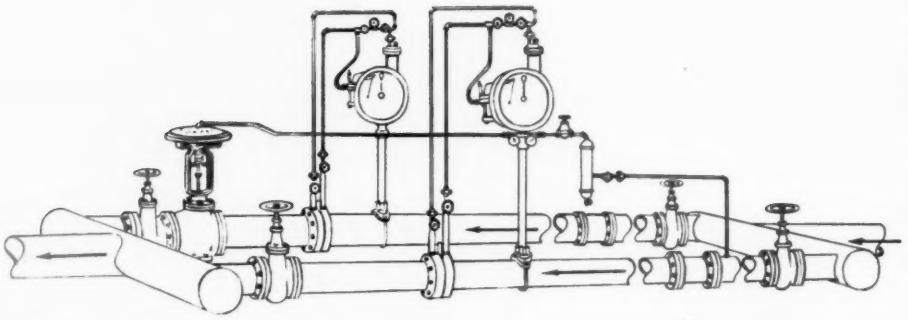


FIG. 9. Recording type differential limit controller installation.

Let us assume that the controller is in service. The differential pointer, or pen, is at zero and below the low index setting, so both high and low nozzles are uncovered. The spring of the lock-up unit has pulled the flapper from its nozzle, and there is no pressure in the diaphragm of the control relay, so its stem is thrown to the left, shutting off the vent and putting full supply pressure on the control valve, which is thus closed. As the differential rises, the low nozzle is covered by its flapper, but nothing happens, for the high nozzle and the lock-up unit nozzle are still uncovered. The differential may range, therefore, from zero to just below the high index with only the primary line in service. As soon as the high index point is reached, however, the high nozzle is covered, which puts pressure in the pusher (1) hydron, moving the lock-up units flapper to the right and covering its nozzle, so that pressure also builds up in the pusher (2) hydron and in the diaphragm of the control relay, which throws to the right, venting the line to the control valve, which thus opens and cuts in the secondary meter. As the flow is now split, the flow through the primary line decreases, uncovering the high nozzle, but nothing happens, for pressure in pusher (2) hydron holds pressure in the rest of the pneumatic system. It is thus seen that if the pointer is positioned anywhere between the two indexes, the measuring system will operate either with the primary line alone or with both lines in service. The determining factor is which index setting was reached last. Reverse action is obtained by changing the control relay to the opposite type. At constant line pressure, a double meter run as described, will handle a flow range of 12 to 1. Wide range meters on both primary and secondary lines will take care of a flow range of 35 to 1. A third meter run will increase the range to 180 to 1. If the line pressure drops with increasing flow, the above ranges are decreased by the ratio of the square roots of the absolute pressures. If the line pressure is higher during the higher flow, the ranges are increased correspondingly.

The use of the pilot type lock-up mechanism permits consistent repeatability of cut-on and cut-off points. One might say that this control holds the control point. This characteristic is most important at the low setting, because an erratic cut-off at this point would result in a substantial loss of range, and a wide range is the characteristic that differential limit controllers are installed to obtain.

The same mechanism may be operated by a pressure element to open a second flow line around the primary choke of a high pressure gas well. Effective on-off action here is imperative, because throt-

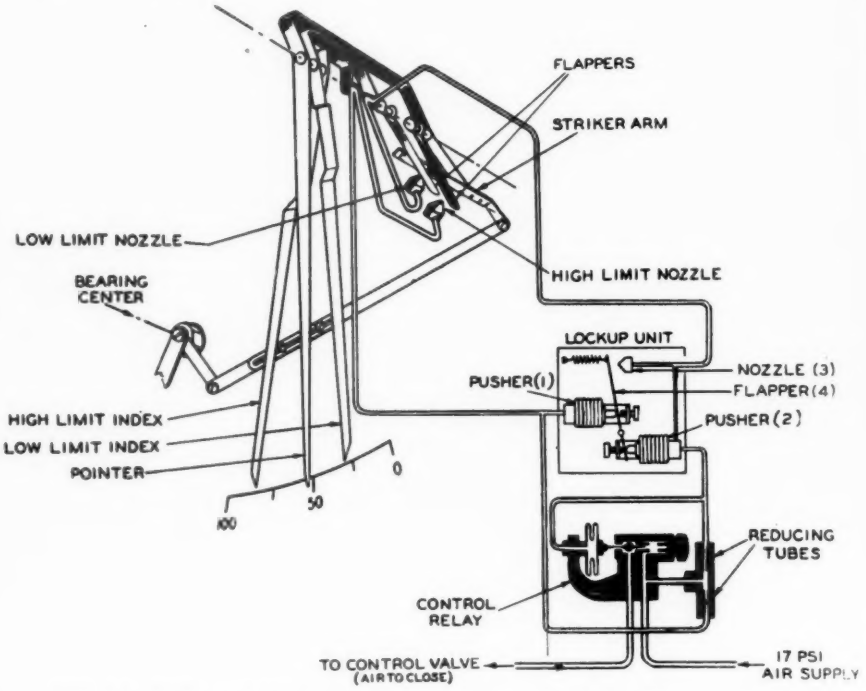
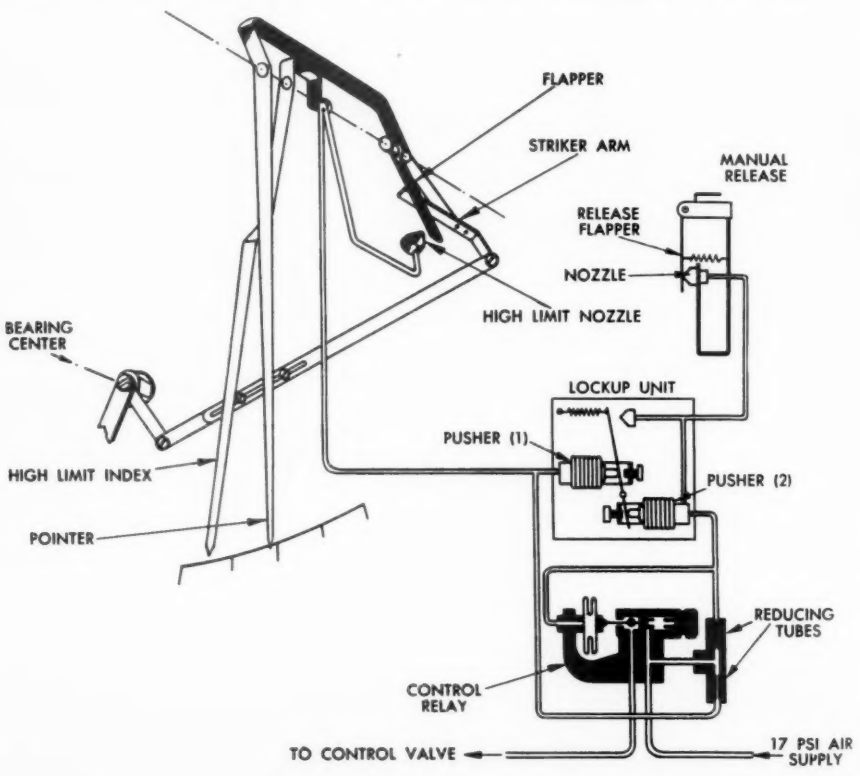
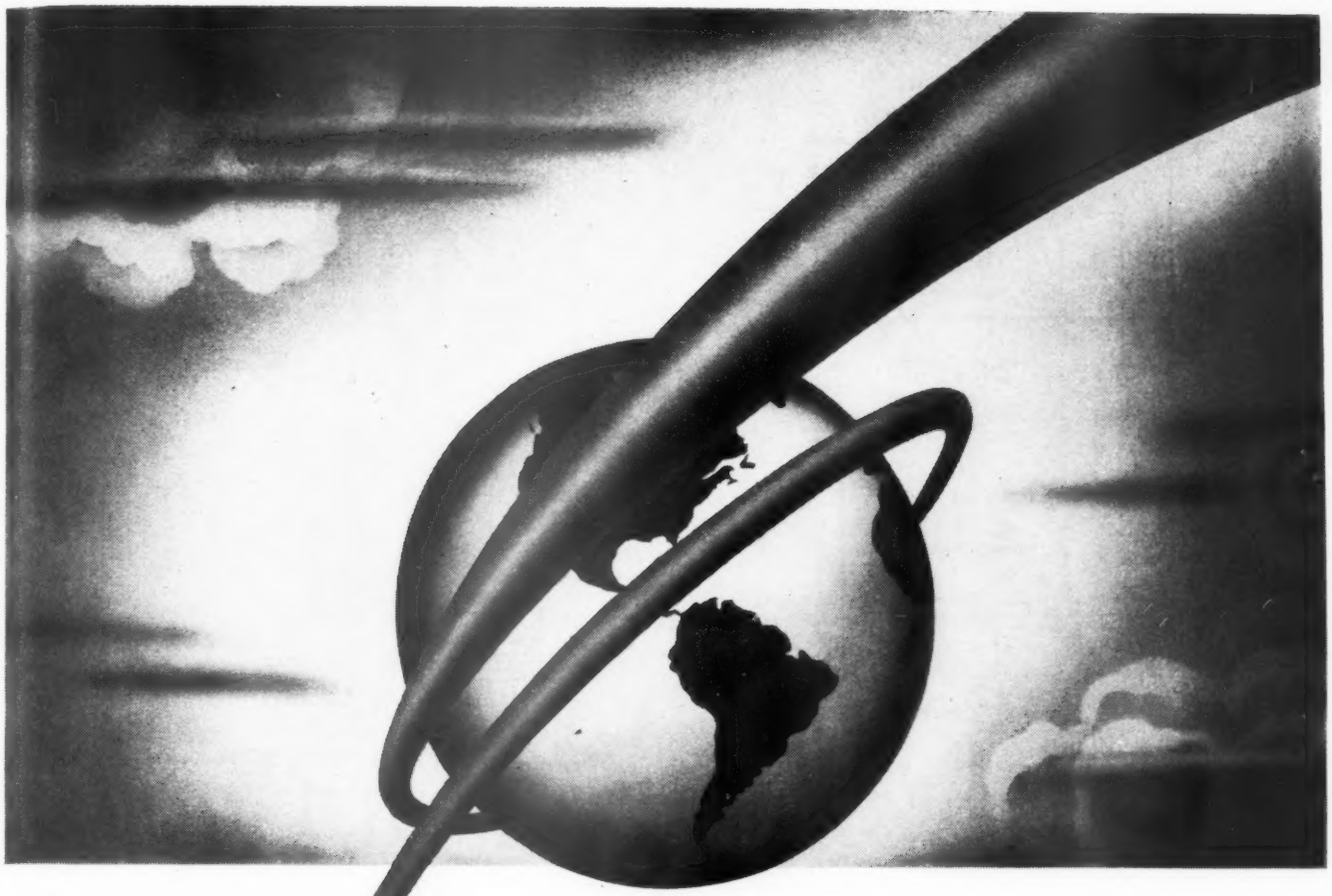


FIG. 10. Differential limit control mechanism for "on-off" control valve.

FIG. 11. Control mechanism for "on-off" control valve with manual release.





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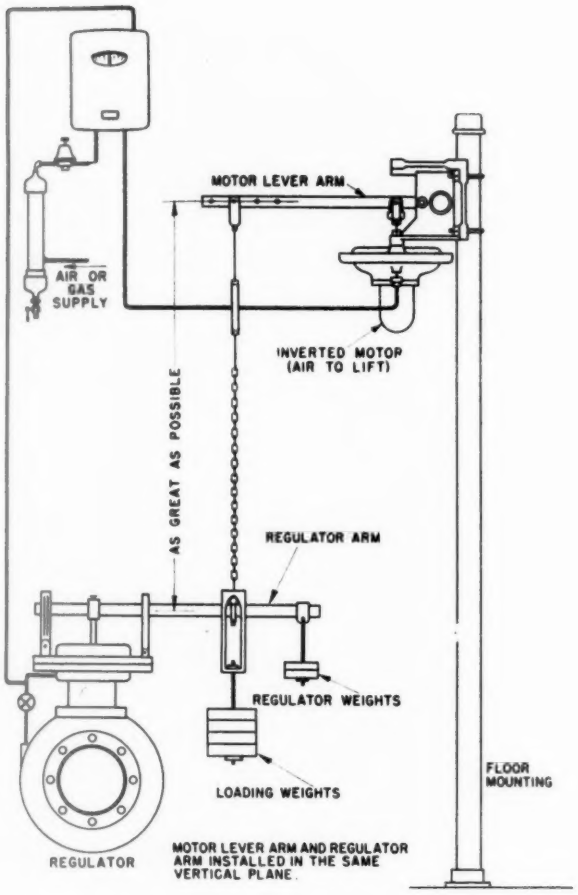


FIG. 12. Proportional pressure controller with adjustable index setting and weighted regulator.

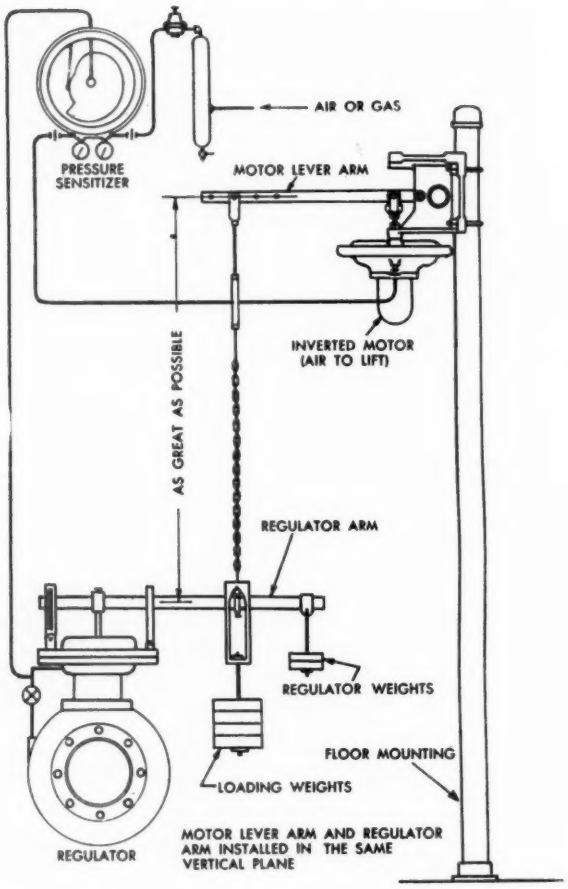


FIG. 13. Proportional pressure controller with time-cam type pressure sensitizer and weighted regulator.

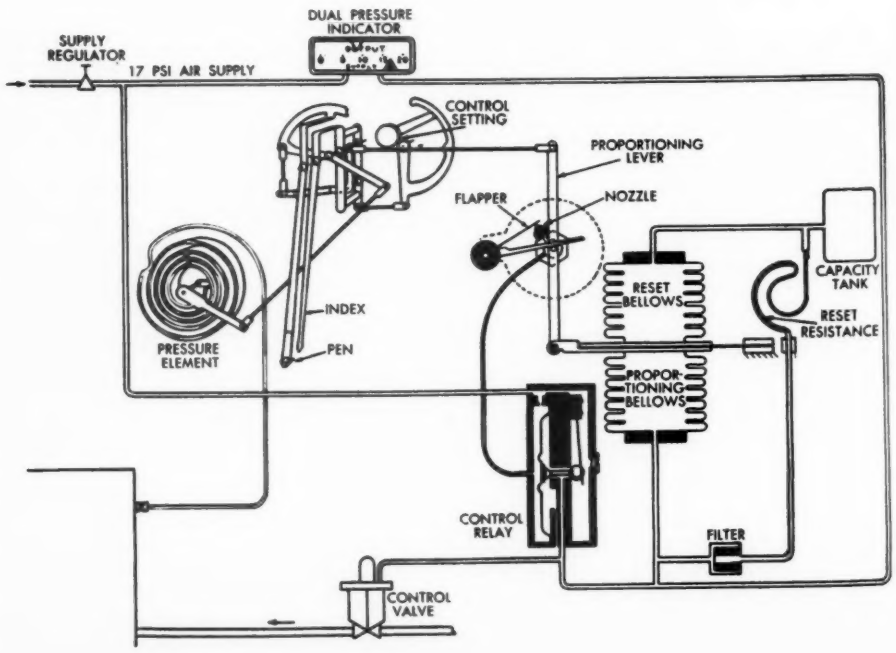
tling through the control valve might cause the lines to freeze.

A similar on-off type of instrument with this lock-up mechanism may be used for alarms and safety shut downs as shown in Fig. 11. In such cases the controller stays locked up until it is manually put back in service by pressing the manual release button. Although a high limit lock-up is shown here, it is obvious that a low-limit lock-up may be effected just as readily. It is also possible to have the lock-up occur at either high or low settings by using a modified two-index instrument.

The pneumatic alarm system should be preferable in dangerous places. Large losses of gas, due to pipe line breaks, may be avoided by the use of such devices, which close shut-off valves when excessive flow occurs in either direction.

● **Proportional control mechanism.** It should be noted in Fig. 8 that the control mechanism is exactly the same as the on-off type except that the proportioning bellows are connected to the output pressure of the control relay. If the measuring element moves the pointer to the right, the flapper tends to move away from the nozzle, thus decreasing the pressure on the control relay diaphragm. This decreases the air supply through the ball seat and increases the vent, resulting in decreased output pressure. As the proportioning bellows are connected to this output, it contracts to hold the

FIG. 14. Schematic diagram of "Proportional with Reset" Controller.



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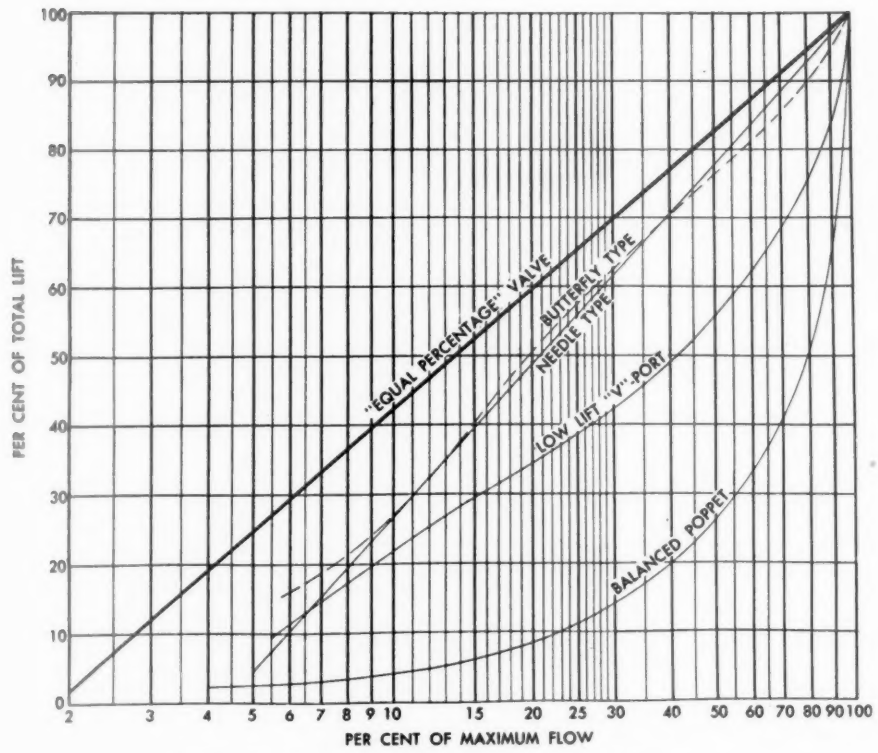


FIG. 15. Flow curves of several types of valves.

nozzle in proper relation to the flapper, thus maintaining balance in the system. When proportional controllers are operating within the proportional band, the flapper and nozzle are always just touching. Otherwise the control relay would put either zero or full supply pressure on the control valve, resulting in its being either wide open or fully closed depending on its action. The width of the proportional band is changed by varying the loading of the proportioning spring, which is a circular cantilever type. Opposite control action is obtained in the same manner as described under on-off control. The proportional band can be adjusted from ¼ of 1 per cent to a maximum of 10 per cent of the indicating scale.

Proportional control is used in the gas industry for pressure control where comparatively narrow throttling ranges and small offset or drift is desired.

Proportional pressure controllers are often used in conjunction with weight-loaded regulators to provide closer control.

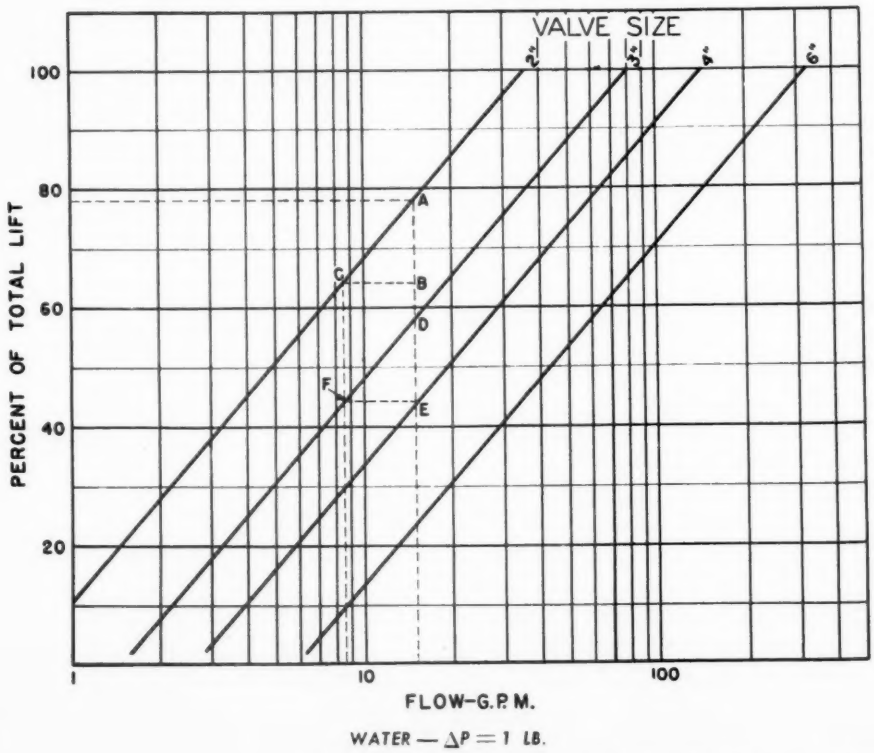
When used for this application, the proportional control known as a "Pressure Sensitizer." The main types used are: (1) The constant pressure type with adjustable index setting, and (2) the time-cam type. The former is used where it is desirable to maintain closely a predetermined pressure setting. Under changing load conditions, most weight-loaded regulators permit substantial changes of controlled pressures. It would be necessary without a pressure sensitizer, therefore, to have an operator constantly in attendance to increase or decrease the weights on the regulator arm, to maintain the output pressure closely.

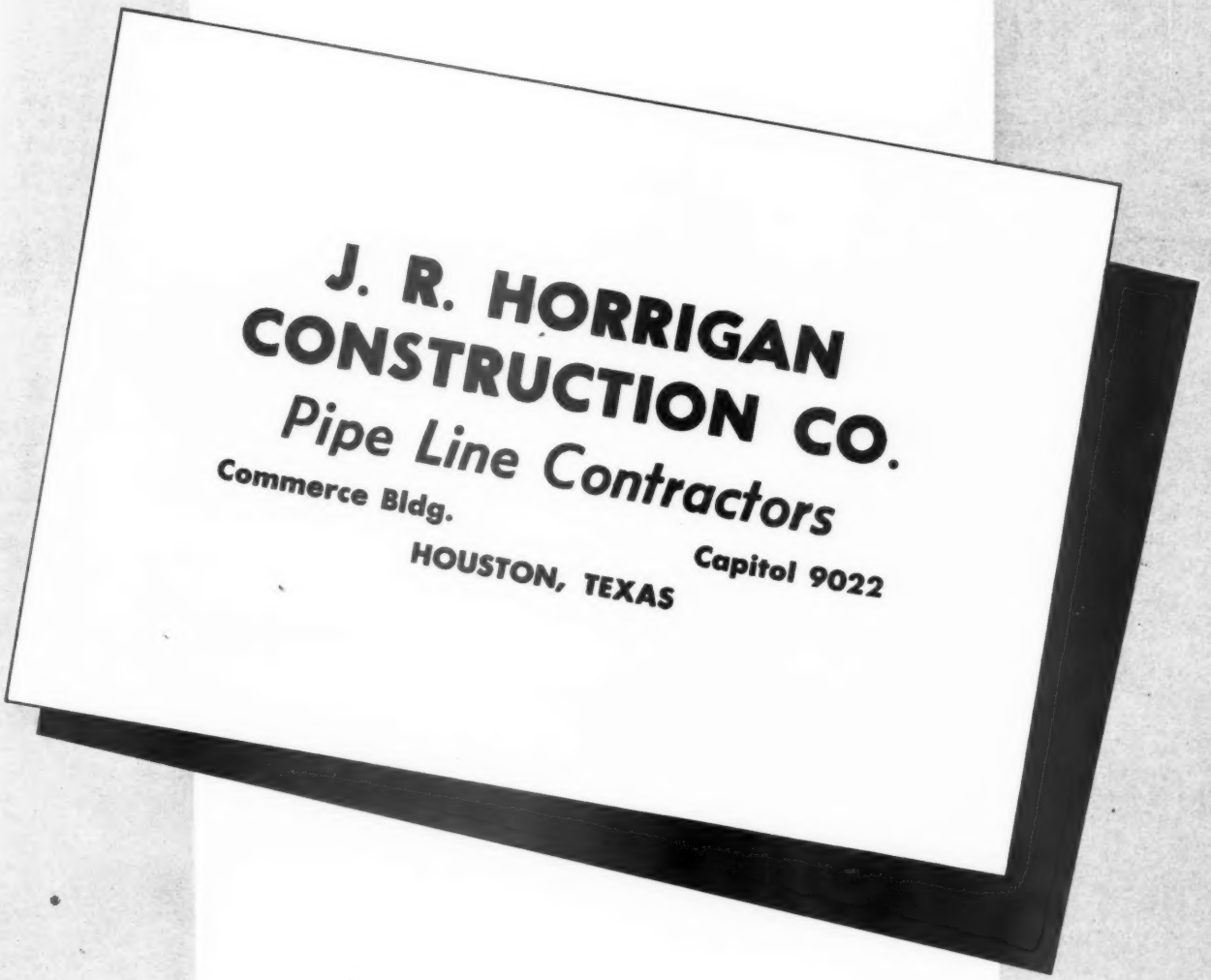
Fig. 12 shows how the pressure sensitizer changes weights automatically. The instrument, a proportional type controller, operates through a diaphragm motor lever to increase or decrease the loading of the regulator. This motor lever arm is attached through a chain and turnbuckle to a slotted yoke, which carries sufficient additional loading weights to hold maximum pressure at maximum demand. Minimum pressure at minimum demand is set by the regulator weights alone, that is, with the yoke mechanism and its loading weights lifted from the regulator arm. The pressure sensitizer acts continuously to vary the loading between these two extreme conditions, so as to maintain very closely the desired output pressure. If the controlled pressure tends to drop, the instrument bleeds pressure from the diaphragm motor, thus increasing the loading on the regulator arm. If the pressure tends to rise, the opposite happens. Note that this control arrangement would fail "safely" in the event of instrument or diaphragm motor trouble, that is, it would load the regulator arm to the maximum, and the regulator would continue to operate at high pressure.

The time-cam type of pressure sensitizer is very similar except that the output pressure is changed in accordance with a predetermined schedule, which is cut out on an aluminum cam that is rotated by a clock, so as to hold a given pressure at a given time. Fig. 13 shows this type of control, which is sometimes used at town-border pressure-reducing stations for packing transmission lines in advance of loads. Seasonal variations of the schedule are made by changing cams.

The proportional type of flow controller may be used for controlling the amount of gas injection into wells for pressure maintenance or repressuring when load conditions are fairly steady. If the control valve is installed upstream from the orifice plate, pressure at the orifice is comparatively constant. The instrument thus becomes a volume controller, although it controls only the differentials across the orifice plate.

FIG. 16. Flow curves of several sizes of "equal percentage" valves.

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● **Proportional with reset control mechanism.** It is desirable or necessary in many processes, for a controller to hold a predetermined control point with no drift. This is particularly true in control problems where wide proportional bands are necessary to prevent cycling and where very close control is essential for satisfactory plant operation. As proportional controllers have a band of control instead of a control point, they are not suitable for such processes for even moderate changes in demand or supply would result in substantial changes in the value of the controlled variable. A control action, which is designed to return the controlled variable to the control point, is known as a "proportional with reset" control.

This type controller is shown in Fig. 14. The nozzle assembly is fixed as concerns vertical or lateral motion, but it may be rotated to change the width of the proportional band and to obtain the opposite control action. The flapper is operated by the contact arm, which is moved by the proportioning lever, and this in turn receives its motion from measuring element. The simplest way to explain the action of this type of controller is to assume that a process is in balance with control maintained at the control point when 8 psi pressure is on the control valve diaphragm and in the proportioning and reset bellows. If a disturbance occurs that causes the measuring element to read higher, the top part of the proportioning lever will be moved to the left, pivoting about the lower end of this lever. This will cause the flapper to more nearly cover the nozzle and thus put more pressure on the diaphragm of the control relay. The supply valve in the relay will open wider and increase the output pressure until the proportioning bellows expand enough to hold the flapper in the proper relationship with the nozzle. The increased pressure in the proportioning bellows establishes a differential pressure between the proportional and reset bellows. This differential pressure is proportional to the pen deviation. The differential pressure produces a flow through the adjustable reset resistance into the reset bellows. As the pressure in the reset bellows rises, the pressure in the proportioning bellows rises the same amount, maintaining the differential pressure established by the pen deviation. This resetting action will continue until the measurement returns to the control point, where the pressures in the proportional and reset bellows become equal and equilibrium is again restored. It is apparent that the controller is now operating with a different valve opening, but control is still at the control point. In other words, instead of the control point shifting in the proportional band with change in load, the proportional band actually shifts about the control point.

Flow ratio controllers should be the proportional with reset type as close control is generally required under varying load conditions. This instrument consists of two meter bodies mounted on a case that contains a mechanism for varying the desired ratio between the two flows. The primary flow, which is usually uncontrolled, determines the control point of the secondary or controlled flow. As the primary flow varies, the secondary flow is increased or decreased to maintain the desired ratio between the flows. The ratio setting can be changed readily in the instrument. If both flows are controllable, the solution, of course, is to use two flow controllers.

In compressor control where control is effected through the engine governor or by a control valve in the steam line of the engine, the application requires a rather wide proportional band. As load changes may vary widely and as close control is advisable, the proportional with reset type of control is recommended.

● **Control valves.** In the same way that a flow meter needs a primary device in the line for a complete metering installation, a controller instrument needs a control valve to complete its installation. With on-off controllers, capacity and positive shut-off are essential valve characteristics. With throttling controllers, proportional or proportional with reset, attention should be given to the changes that occur in the supply of the controlled medium, that is, the amount of correction needed when the valve changes from one position to another. In simple problems of gas pressure regulation, valve characteristics may not be of much importance. In more difficult problems where unfavorable lags may complicate the control problem, valve characteristics may assume critical importance.

Fig. 15 shows flow curves of several types of valves plotted on semi-log paper. The ordinates reading "per cent of total lift" might also have a scale reading "pressure on diaphragm of control valve." The heaviest line has what is known as equal percentage characteristics. By that we mean that equal changes in pressure on the diaphragm of the valve increase or decrease the flow by equal percentages of the existing flow regardless of the valve position at the time of the change. For example, at 10 per cent lift, the flow through the valve is 2.75 per cent of maximum. At 20 per cent of lift, the flow becomes 4.1 per cent of maximum, or an increase of 50 per cent over the previous flow. Farther up the scale, for example, at 40 per cent lift, the flow through the valve is 9.2 per cent of maximum. With the same increase in pressure, that is, to 50 per cent lift, the flow becomes 13.8 per cent of maximum. This is likewise a 50 per cent increase over the previous value. At a third point on the scale, namely, 80 per cent of lift, the flow through the valve is 45 per cent of maximum, and at 90 per cent of lift (again the same increase in pressure on the valve), the flow becomes 67.5 per cent of maximum, or a 50 per cent increase over the previous flow.

The practical value of this percentage characteristic may be brought out by examples. Let us assume that a control valve in the steam line of a reboiler at a natural gasoline plant keeps the process balanced with 10 psi pressure on the diaphragm of the valve and a certain pressure drop across the valve. A given process disturbance requires a 10 per cent change in steam flow to keep the process balanced, or the steam supply pressure may be lower at another time, so the valve, in order to pass the same amount of steam, must be open wider as the pressure drops.

Fig. 16 shows how valve lift may be plotted against rate of flow. Valve sizing is of rather minor importance with equal percentage valves of wide range. For example, if a 2-in. valve is operating at 78 per cent lift (A), a 3-in. valve on the same application would operate at 58 per cent lift (D) to pass the same flow. Now if a change in load occurs that would cause the 2-in. valve to drop to 64 per cent lift (C), this change would, of course, affect the 3-in. valve in a like manner. To decrease the flow the same percentage, the 3-in. valve would change to 44 per cent lift (F), an equal percentage decrease. In other words, triangles A B C and D E F are similar and equal. Hence, no change in controller adjustments would have to be made, if one valve were substituted for the other. Although operators should not be encouraged to install oversize control valves, it is interesting to note that the wide range, equal percentage valve just described will handle such control problems effectively.

Correct sizing of equal percentage valves is not critical, provided that the size is ample for maximum demand and that the range may be increased without the necessity of changing the controller settings.

In conclusion, we have seen that on-off control may be applied in the gas industry for special types of situations. Proportional type controls may be applied where narrow proportional bands can be used. Where a wide proportional band is necessary, extremely close control is essential, or if widely changing load conditions are present, the proportional with reset type control should be applied. Control valve characteristics should receive careful consideration on all control problems involving unfavorable lags. ★★★

Seek uranium ore

The Soviet Union is estimated to employ up to 40,000 workers in its hunt for uranium in Germany and Czechoslovakia, according to observers in Berlin. The Czech uranium mines, said to be richest in Europe, produce about 15 tons a year and the German mines about half that. Plans are to increase Czech ore production from 24 to 140 tons in 1952.

Workers are using uranium detectors in abandoned silver and salt mines and even go through old piles of waste ore thrown away when the mines were producing a half century ago.

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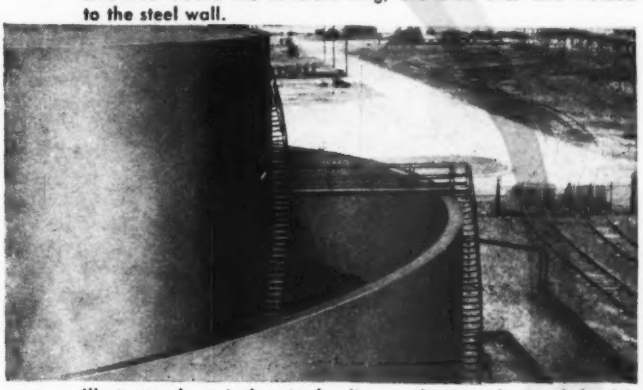
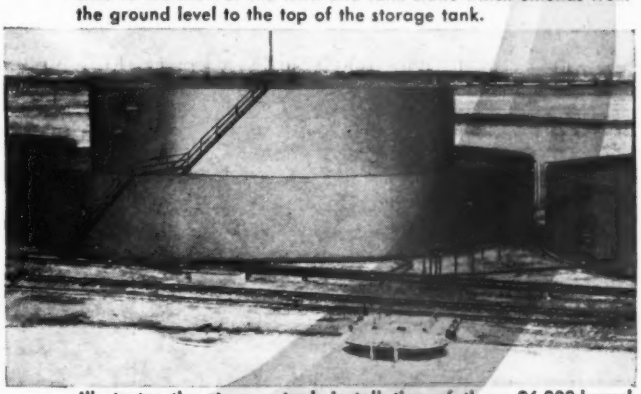
The HAMMOND STEEL DIKE and STORAGE TANK INSTALLATION, illustrated, was designed and erected for the Coastal Oil Company at their Port Newark terminal. Each of the three cone roof tanks has a capacity of 96,000 barrels and each dike has the equivalent capacity. The tanks are 48 feet high and 120 feet in diameter and the dikes are 24 feet high and 172 feet in diameter.

Conventional earthen dikes would have required at least six acres more ground space than was used for these steel dikes and costs of reinforced concrete dikes would have been much higher.

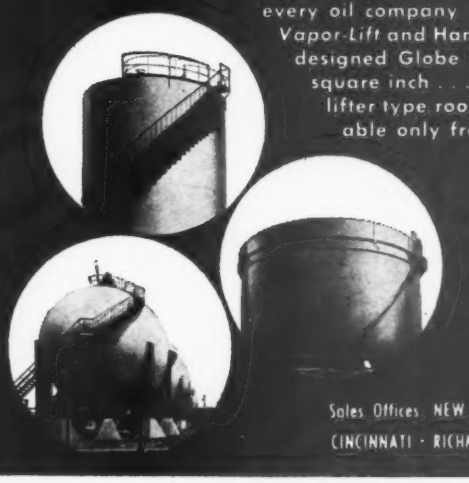
1. Illustrates the concrete foundation ring for one of the steel dikes, with part of the first ring of steel plates in position. After a steel dike wall is erected and welded, the reinforcing bars, shown extended above the concrete ring, are bent over and welded to the steel wall.



2. Illustrates the spiral stairs leading to the top of one of the 24-foot-high steel dikes and also the walkway leading from this dike to the shell of the tank and tank stairs which extends from the ground level to the top of the storage tank.



3. Illustrates the storage tank installation of three 96,000-barrel cone roof tanks with the steel dikes, 24 feet high and 172 feet in diameter.



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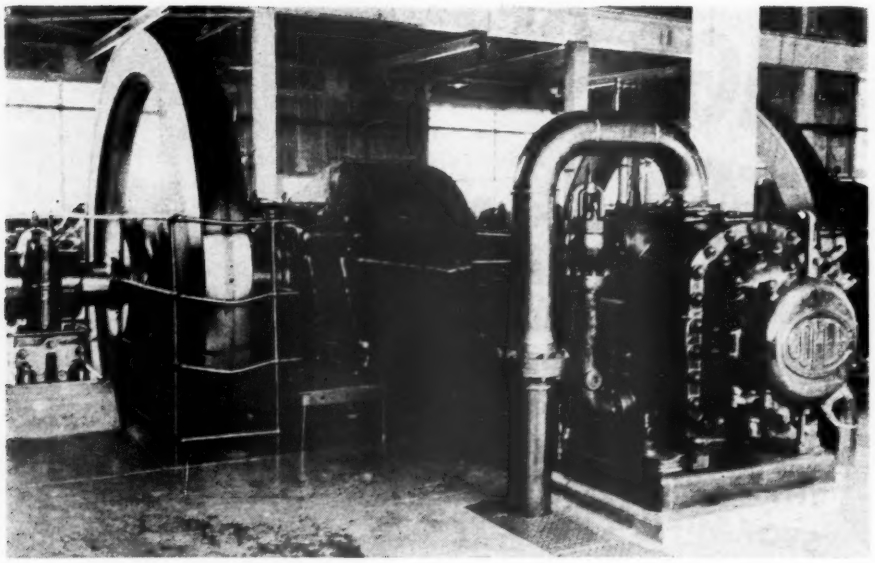


FIG. 1.

Cooling water for gas booster stations*

By A. V. MUELLER†

THE importance of natural gas for industry and homes became quite pronounced during the winter of 1946-47 when there was a shortage of fuel—coal as well as oil and gas.

Natural gas is found in many parts of the United States and is carried by pipe lines through compressor stations where it is compressed to a higher pressure for delivery to the consumer, sometimes great distances away.

In these stations the gas goes through various processes that require the operation of machinery and equipment, such as gas-engine-driven compressors, cooling towers, pumps, etc.

The station described in this article belongs to the Columbia Gas System and is operated by the Ohio Fuel Gas Company, Ashland district, A. R. Fitzgerald, chief engineer. It is of special interest to manufacturers of turbine pumps because all water pumping is done exclusively by turbine pumps.

The older of the Columbia Gas System's stations are equipped with regular centrifugal pumps, such as vertical sump pumps of the dry pit type, and horizontally split casing double suction pumps. Both types require a great deal more space than vertical turbine pumps, which are submerged and do not need any foot valves nor any suction lines and are always primed and ready to start.

The saving of space and the fact that the overall efficiencies were in favor of the turbine pumps, the Columbus district engineer, F. F. Fisher, decided to try several stations in his territory with close coupled turbine pumps.

There are three Columbia stations situated near Mansfield, Ohio, within a radius of 25 miles, all equipped with Deming turbine pumps.

The Ohio Fuel Gas Company's plant is so-called "B" station, pumping to the Pavonia plant, an "A" station, which is the main station, collecting gas from all others in the neighborhood and delivering direct to the market.

The gas received at the Ashland district station comes from about 600 wells of a maximum radius of 20 miles. The piping system from these wells is a network of small and larger pipes, finally reaching the station in two 12-in. lines, one called the line from the high pressure field and the other from the low pressure field.

The pressures under which they reach the station vary; they range from 14 lb to 80 lb.

The Ashland station is equipped with the following essential machinery:

1—Blaw-Knox gas cleaner.
2— 450-hp Worthington Snow engines.
1—1150-hp Worthington Snow-Duplex engine.
1— 350-hp Cooper-Bessemer gas engine (Fig. 1).
1—Marley double cooling tower with two fans for induced draft.
6—Deming turbine pumps as follows:
2—Fig. 4700 12-in. two-stage, 1000 gpm against 60-ft head, 20-hp at 1750 rpm for engine and compressor jacket cooling.
2—Fig. 4700 16-in. one-stage, 1500 gpm against 30-ft head, 15-hp at 1150 rpm, pumps warm water over cooling tower.
1—Fig. 4700 8-in. two-stage, 250 gpm against 30-ft head, 3-hp at 1750 rpm, for water supply from pond to cooling tower basin.
1—Fig. 4700 10-in. one-stage, 500 gpm against 30-ft head, 5-hp at 1750 rpm for replenishing pond from river one-half mile away.

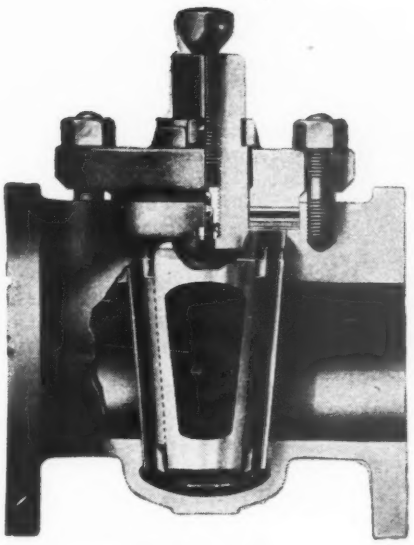
Each of the engines is operated by natural gas and they are direct-coupled to compressors. Engines and compressors are jacketed for water cooling.

The gas upon entering this station is scrubbed by a Blaw-Knox gas cleaner. When the scrubbing process is completed the gas proceeds to the compressors, usually entering at a pressure of 14 psi. To carry away the heat generated in the cylinders of the gas engines and the cylinders of the compressor jacket, water is pumped through both.

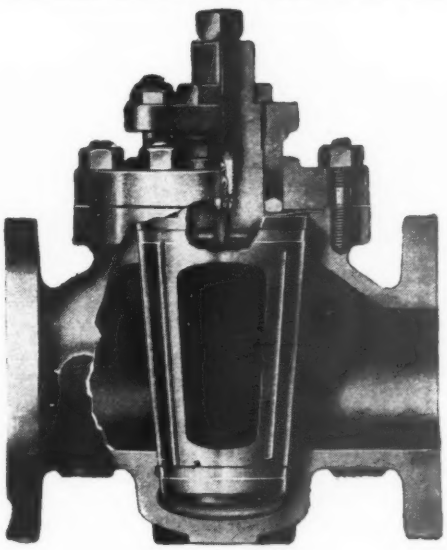
The cooling tower is of wooden construction, mostly redwood, 35 ft high, 46 ft long, and 22 ft wide. The concrete reservoir under the tower is about 7 ft deep and extends on one end 10 ft beyond the tower (Fig. 2). The small

*Presented before the National Association of Vertical Turbine Pump Manufacturers, October, 1947, under the full title, "Cooling Water Requirements for Natural Gas Booster Stations."

†Manager, Centrifugal and Turbine Department, The Deming Company.



Single Gland Type



Regular Gland Type

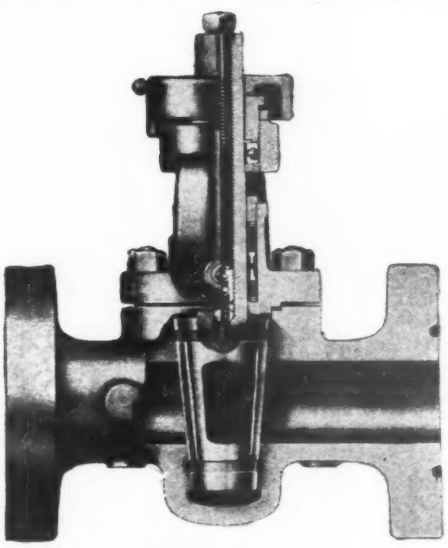


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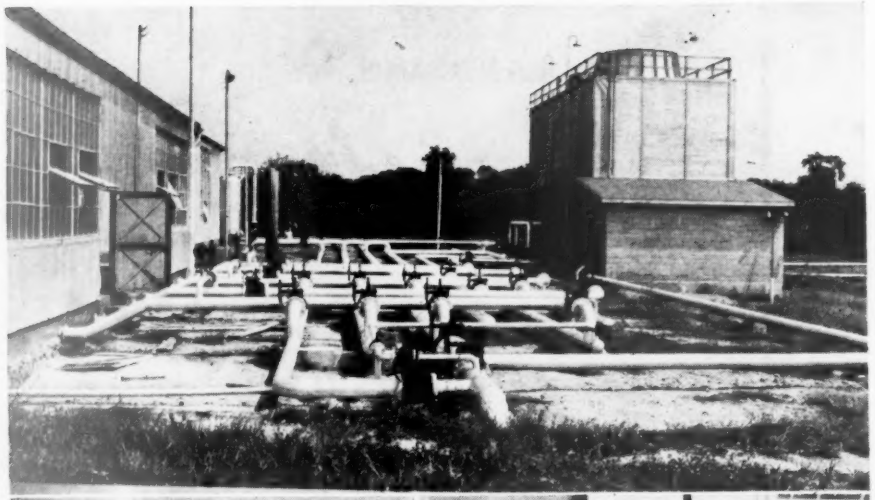
FIG. 2.



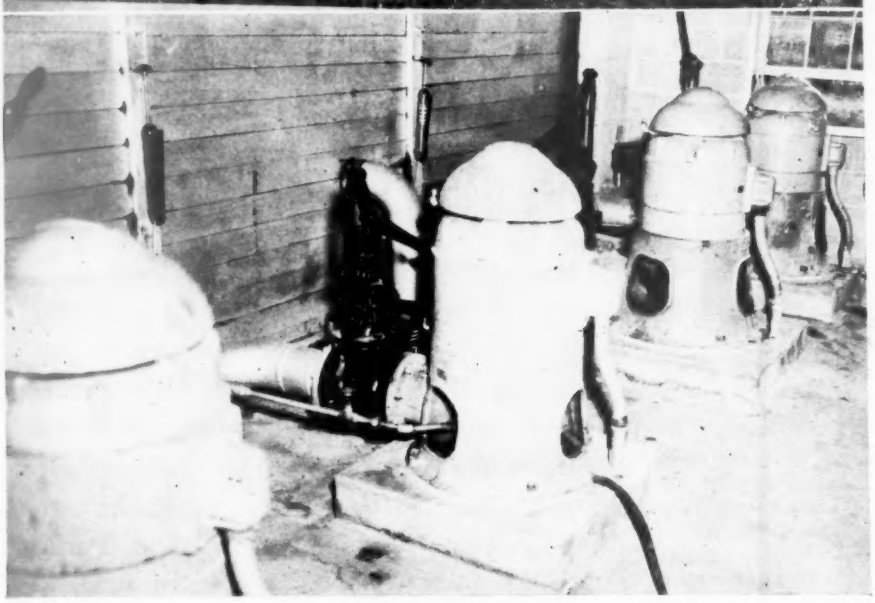


FIG. 3.

building of 10 ft and 22 ft floor space above this extension houses four Deming turbine pumps.

This reservoir is divided in the middle, one-half being a cold water sump and the other the hot well. In the foreground of Fig. 3 the motors and discharge heads of the two 1000-gal pumps are seen placed above the cold water sump while the two 1500-gal pumps in the background are over the hot well.

The tower is divided into two separate compartments, each compartment having a large circulating fan set in the roof. One compartment contains the cooling coils for the intercoolers and aftercoolers from the compressors. The warm water fom this compartment is collected in the hot well, which also receives the warm water from the engine and compressor jackets. The other compartment collects cool water for use in the cold well.

As will be noted, the position of the levers on the first and last pumps indicate that the valves are open and, therefore, these two pumps are in operation. The middle pumps are duplicates of these and to equalize the wear operate on alternate weeks with the first two.

The distance from pump house floor to the bottom of the Keystone strainers of each of these four pumps is 7 ft.

Gas is admitted to the compressors, usually at 14 psi pressure. The first stage of compression raises the pressure from 14 psi to 68 psi. Leaving the compressor the gas has a temperature of about 220 F and is conducted through a 12-in. steel pipe line to an intercooler consisting of four horizontal banks of a total of 360 7/8-in. copper tubes connected to inlet and outlet headers. This intercooler is situated in the first cooling tower compartment described above.

The lower section consists of two banks, or 180 tubes, and is 3 ft above the top of the foundation, the upper section consists of the same number of banks and tubes and is situated 2 ft above the lower section.

The gas, after passing through the 360 tubes of the intercooler, returns under a pressure of 68 psi to the pumping station and is further compressed to 198 psi, leaving the compressor with a temperature of 200 F and returning to the aftercooler in the same compartment of the cooling tower as the intercooler. Here it goes through a set of 98 7/8-in. copper tubes arranged in two banks, one above the other, similar to the 360 tubes of the intercooler. When leaving the cooling tower the gas is under 198 psi pressure at a maximum temperature of 85 F, and is ready for delivery into the Pavonia station.

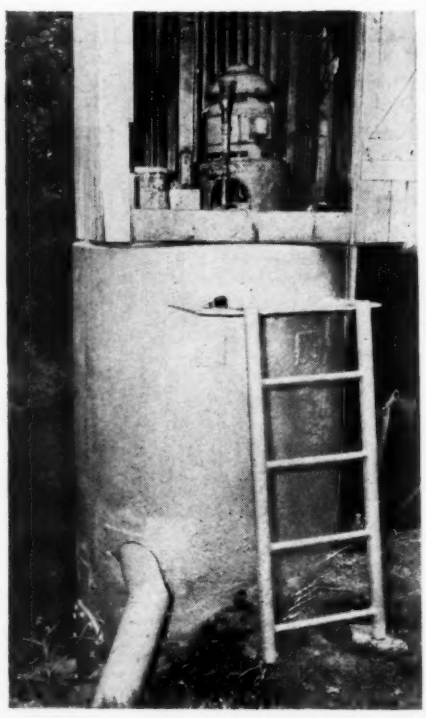
The 100-gal pump takes care of cooling engines and compressors. The water is taken out of the cold well and pumped through the water jackets of engines and compressor and returns without going over the spray tower to the hot well section of the reservoir. Here it is picked up by the 1500-gal pump, which supplies water for the two sections of the towers (356 spray nozzles located on tower). Some of these spray nozzles are in the section for gas cooling and the rest in the other section next to the pump house. The water that comes from the spray nozzles in this section simply goes over the decks of lath, etc. After falling into the reservoir, this water returns to the cold well and is used over again for supplying the water jackets with cool water.

In a cooling tower the spray and cooling action is affected by:

(a) Radiation from sides of tower.
(b) Contact of water with cool air.
(c) Evaporation.
(d) Induced draft.

On top of the tower are installed two fans, one of 116-in. diam and the other 132-in. diam. The gas cooling fan (116-in. diam) is connected by a jackshaft and reducing gears to a 15-hp two-speed electric motor. When operating at 1750 rpm, 15 hp are required, and when operating at 875 rpm, 3.7 hp are required. The jacket water cooling fan (132-in. diam) motor delivers 25 hp at 1750 rpm and 6.2 hp at 875 rpm. Two-speed fans were selected to provide induced draft

FIG. 4



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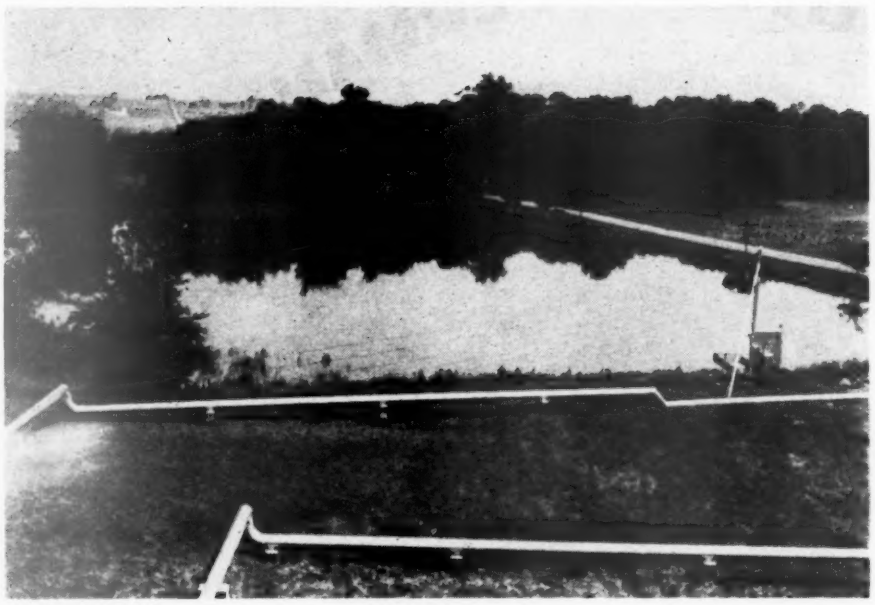

FIG. 5

depending on atmospheric conditions. In winter the fans are not used very much but in hot humid summer days they run continuously. These fans draw the air through the side louvers of the tower, accelerating the air current in the enclosed structure.

● **River pump.** This pump is situated on the river bank about one-half mile from the gas station. It is installed in a concrete pit (Fig. 4), and is protected from the weather by a steel shed. The distance from the bottom of the discharge head to the bottom of the strainer is 10 ft. The discharge line is laid underground and supplies the pond of the cooling tower (Fig. 5). Its operation is automatic and installation is frost proof.

● **Pond pump.** The pond pump is installed in a similar structure as the river pump. In order to keep it from freezing up in the winter time a heater is provided.

This pump operates during unfavorable hot weather conditions about twice daily for a period of 30 min, which is approximately 15,000 gal per each 24 hr.

When the gas leaves the Ashland plant it has gone through a stepping-up pressure process but no moisture or gasoline has been eliminated. This is done at the aforementioned Pavonia station, which has a drying plant. Ashland produces between 26 and 38 million cu ft of gas a day. When the gas reaches Pavonia it is stepped up by compression to 800 psi pressure for delivery to underground storage near markets, and 350 to psi for delivery direct to the market.

From our observation and interviews with the operating engineers of these plants where approximately 30 vertical turbine pumps are installed, we are convinced that this type of pump is more suitable for gas booster stations than other types.

The advantages of vertical turbine pumps may be summed up as follows: (1) High efficiency; (2) ease of installation; (3) easy to maintain; (4) no dry pits required; (5) no suction lines; (6) always primed; (7) will handle some sand and foreign matter without damage, and (8) less piping, fittings, and valves.

★ ★ ★

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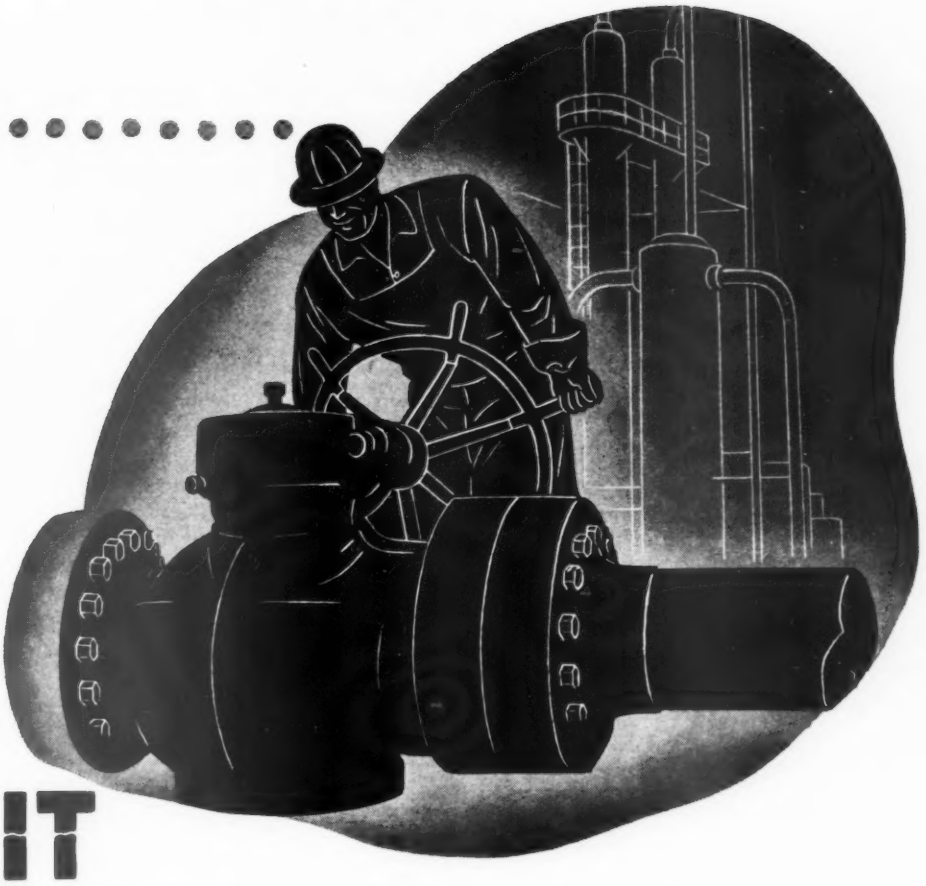

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The list includes papers given before meetings of technical societies, trade organizations, and other groups. What is believed to be the *original source* is given for each item. The name of the organization before which the paper was presented is followed by the place and date of meeting.

The papers are indexed under three classifications to expedite the work of the researcher. They may be found under subjects, under authors, and under organization if presented at a meeting.

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KEY TO ABBREVIATIONS

AAODC—American Association of Oilwell Drilling Contractors.
AAPG—American Assn. of Petroleum Geologists
ACS—American Chemical Society
AGA—American Gas Association
AIChE—American Institute of Chemical Engineers
AIME—American Institute of Mining and Metallurgical Engineers
Anal. Chem.—Analytical Chemistry (edition of Industrial and Engineering Chemistry)
API—American Petroleum Institute
ASME—American Society of Mechanical Engineers
ASTM—American Society for Testing Materials
Can. J. Research—Canadian Journal of Research
Chem. Inds.—Chemical Industries
Chem. Eng. Progress—Chemical Engineering Progress
IPAA—Independent Petroleum Association of America
Ind. Eng. Chem. — Industrial and Engineering Chemistry magazine.
ISA—Instrument Society of America
Jour. ACS—Journal of American Chemical Soc.
J. Inst. Pet.—Journal of the Institute of Petroleum, (London)
J. Org. Chem.—Journal Organic Chemistry
Mid-Continent O&GA—Mid-Continent Oil and Gas Association
NACE—National Association of Corrosion Engineers
NLGI—National Lubricating Grease Institute
NPA—National Petroleum Association
NGAA—Natural Gasoline Association of America
N. Tex. O&GA—North Texas Oil and Gas Association
O&GJ—Oil and Gas Journal
Oil Compact—Interstate Oil Compact Commission
PEPA—Petroleum Electric Power Association
Pet. Refr.—Petroleum Refiner
Proc. Royal Soc.—Proceedings of Royal Society (London)
Rocky Mt. O&GA—Rocky Mountain Oil and Gas Association
SAE—Society of Automotive Engineers
SGA—Southern Gas Association
WPRA—Western Petroleum Refiners Association

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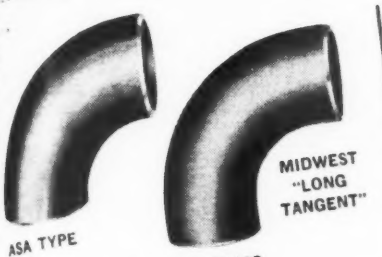


90° ELBOWS

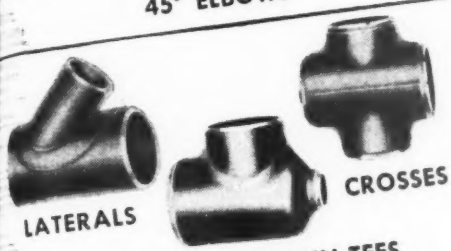
REDUCING ELBOWS

TEES

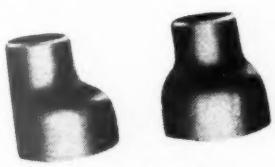
45° ELBOWS

180° RETURNS

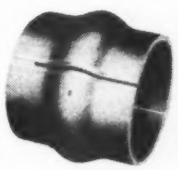
LAP-JOINT STUB ENDS



REDUCING-ON-RUN TEES



REDUCERS

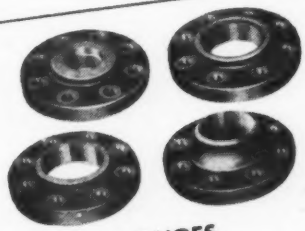


SLEEVES

CAPS

SADDLES

SHAPED NIPPLES



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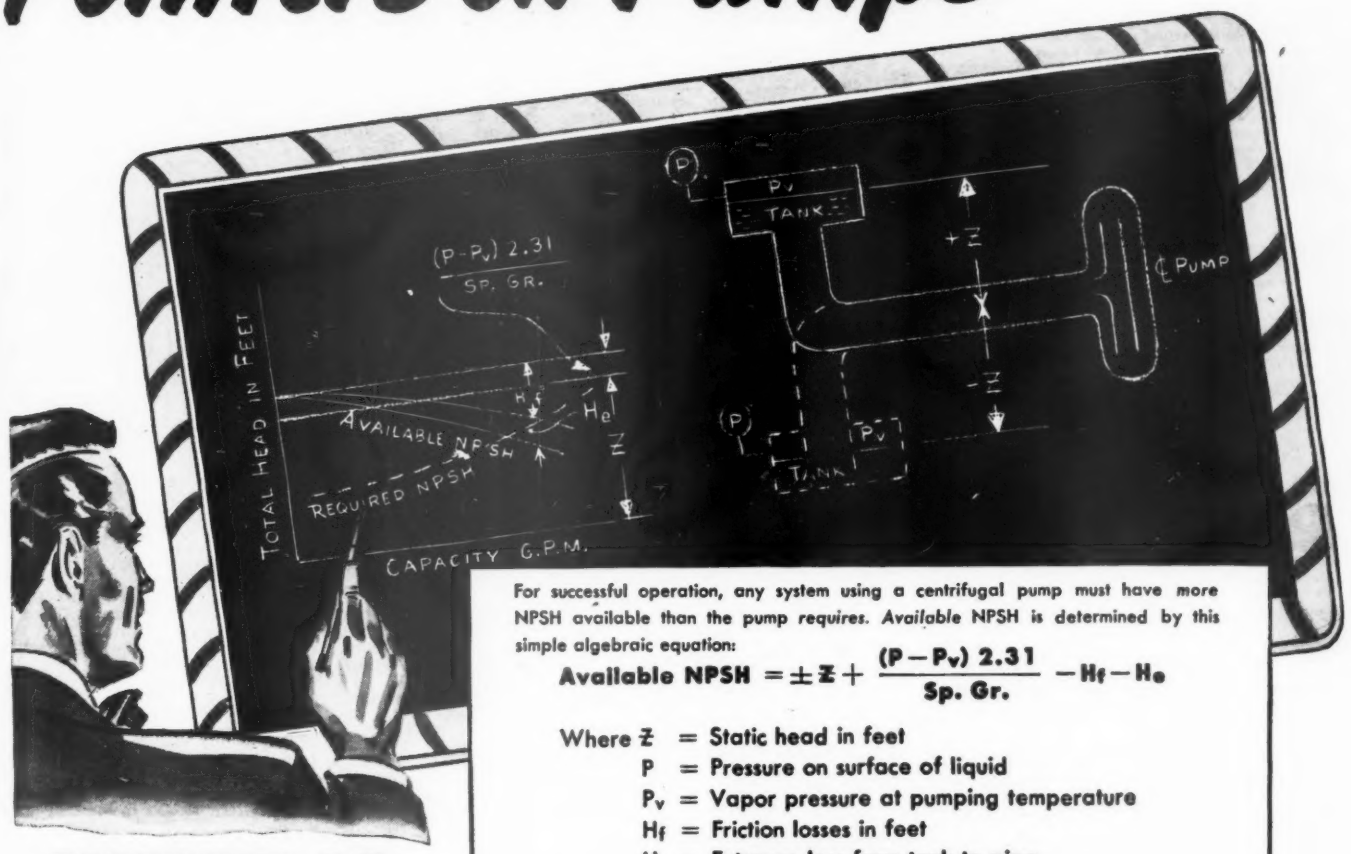
Pointers on Pumps



For successful operation, any system using a centrifugal pump must have *more* NPSH available than the pump *requires*. *Available* NPSH is determined by this simple algebraic equation:

$$\text{Available NPSH} = \pm Z + \frac{(P - P_v)\ 2.31}{\text{Sp. Gr.}} - H_f - H_e$$

Where Z = Static head in feet
P = Pressure on surface of liquid
P_v = Vapor pressure at pumping temperature
H_f = Friction losses in feet
H_e = Entrance loss from tank to pipe

NOTE: For boiling liquids, P usually equals P_v; this item is therefore omitted from the problem.

WHAT IS NPSH?

NPSH (net positive suction head) is an ***absolute*** term covering hydraulic conditions at the suction side of a centrifugal pump. It can be used instead of the ***relative*** terms "suction lift" and "suction head" to assure the proper application of centrifugal pumps. These relative terms are useful in calculating the total head against which the pump must operate; but they should not be used when considering the suction condition as it affects proper centrifugal pump selection.

Actually, every centrifugal pump has its own NPSH characteristic, usually referred to as "required NPSH" The pump impeller opening must be filled at the required rate of flow (GPM) so the impeller can pump at this rate. The velocity needed to put this quantity into the impeller opening must come from an external head. The value of this external head is the "required NPSH".

Obviously, if the liquid pumped is not to vaporize in the entrance to the impeller, the required NPSH must be measured over and above the vapor pressure of the liquid at the pumping temperature. The required NPSH will vary roughly as the square of the pump capacity through the useful range of application of that pump.

For YOUR Pumping Needs

Worthington has the most complete line of centrifugal pumps — all pressures, all capacities — and engineers ready to give you expert advice on any pumping problem. For further details proving *there's more worth in Worthington*, contact our nearest District Office, or write to *Worthington Pump and Machinery Corporation, Centrifugal Pump Division, Harrison, N. J.*

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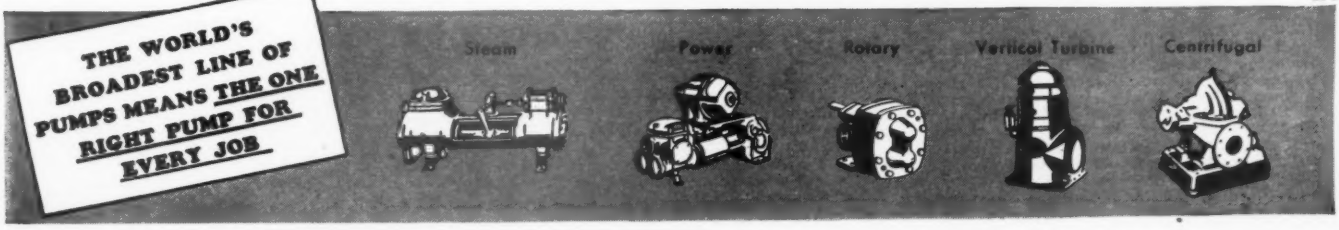

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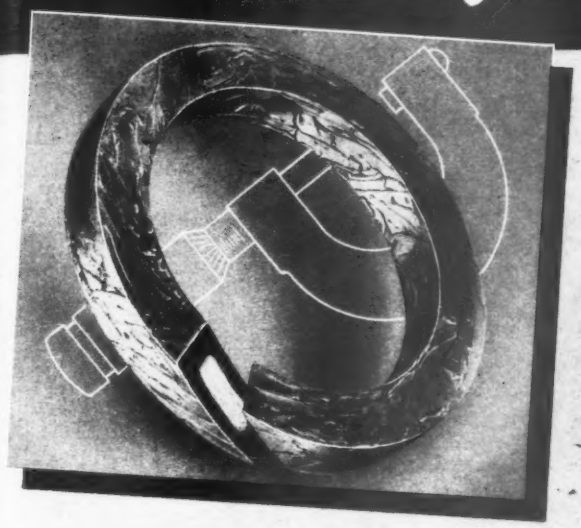

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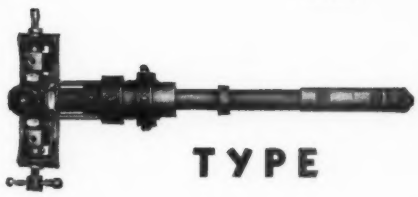

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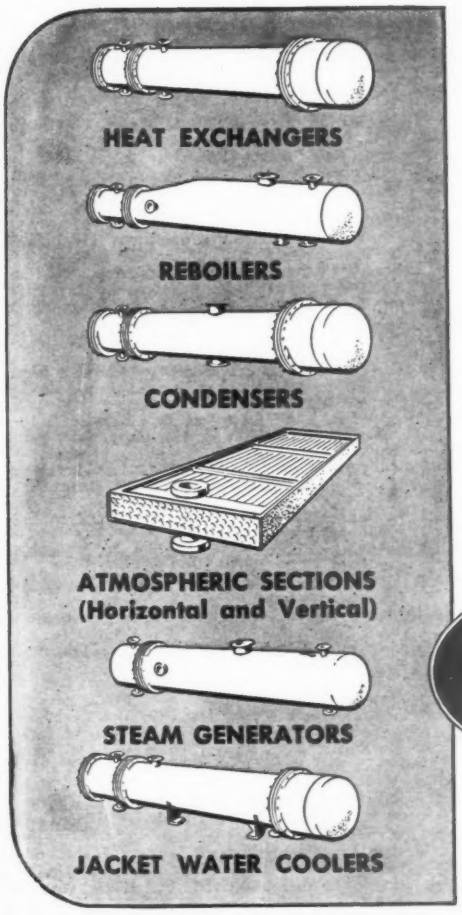

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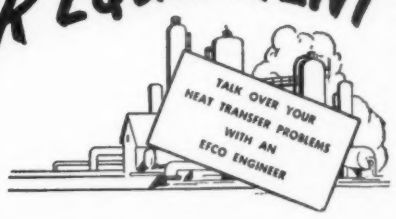

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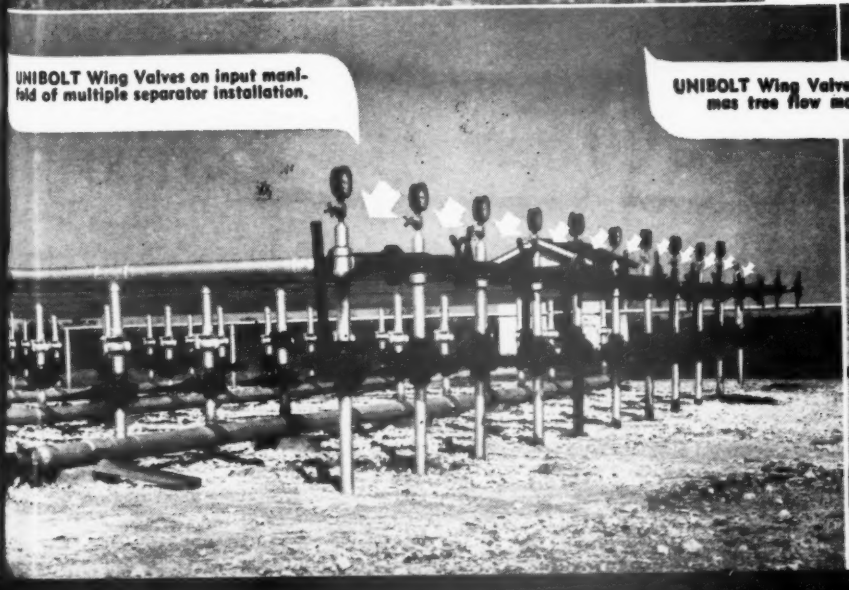

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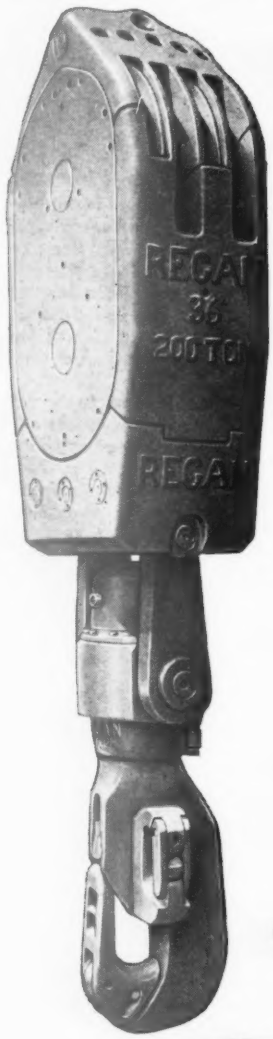

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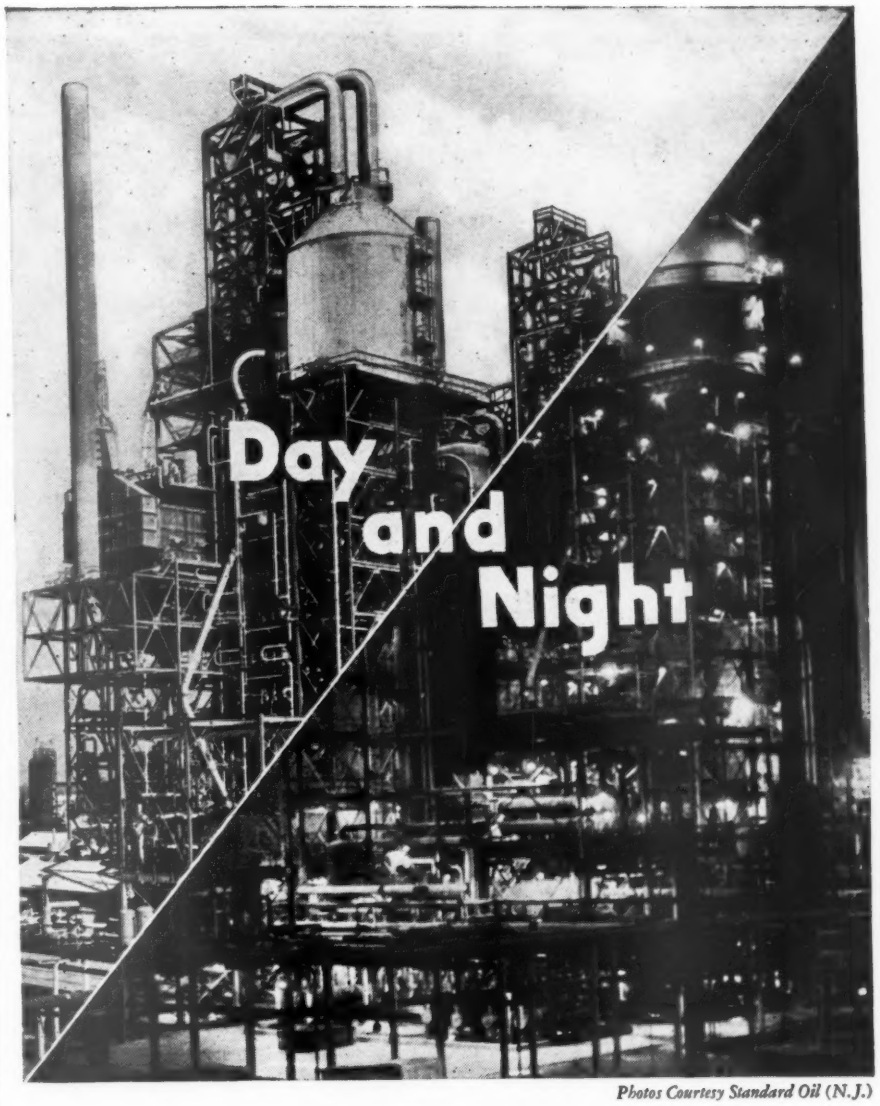

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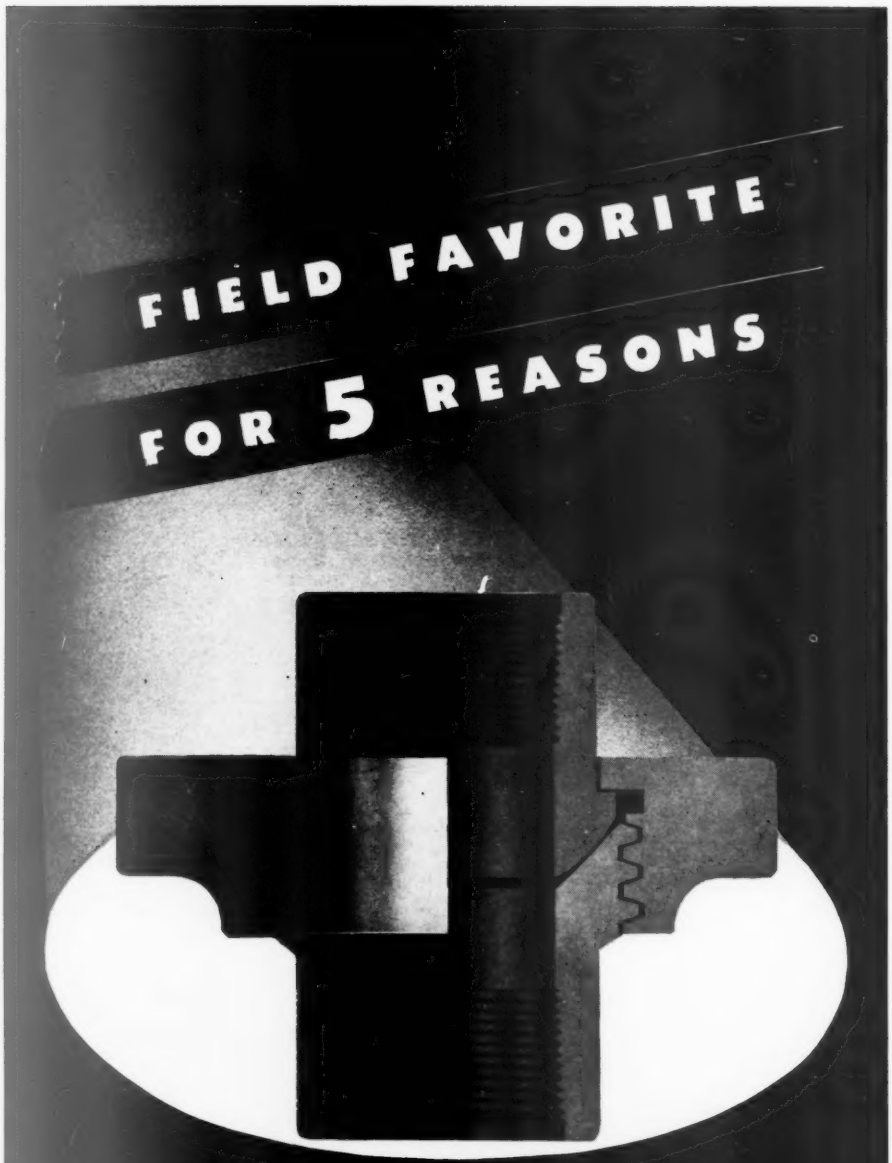

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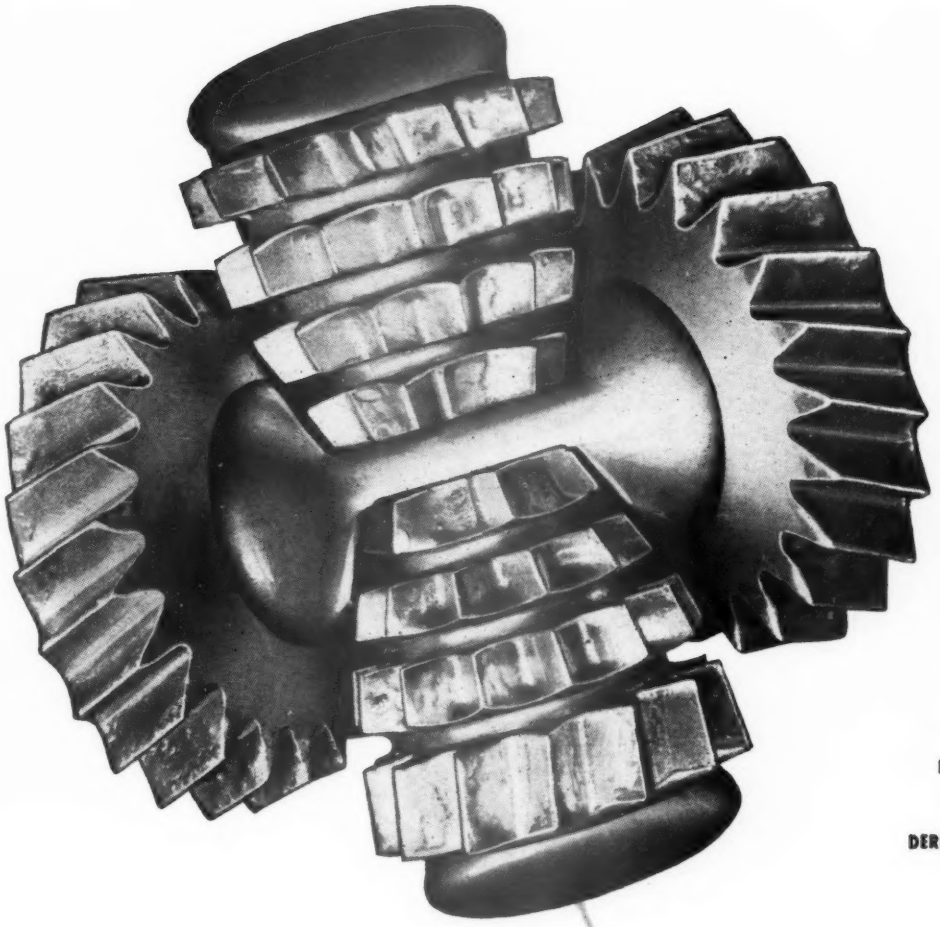

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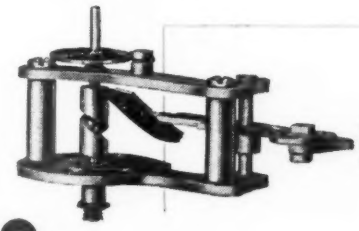

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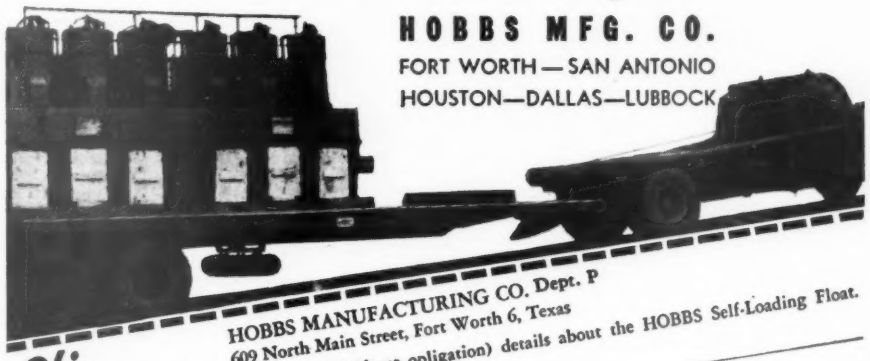

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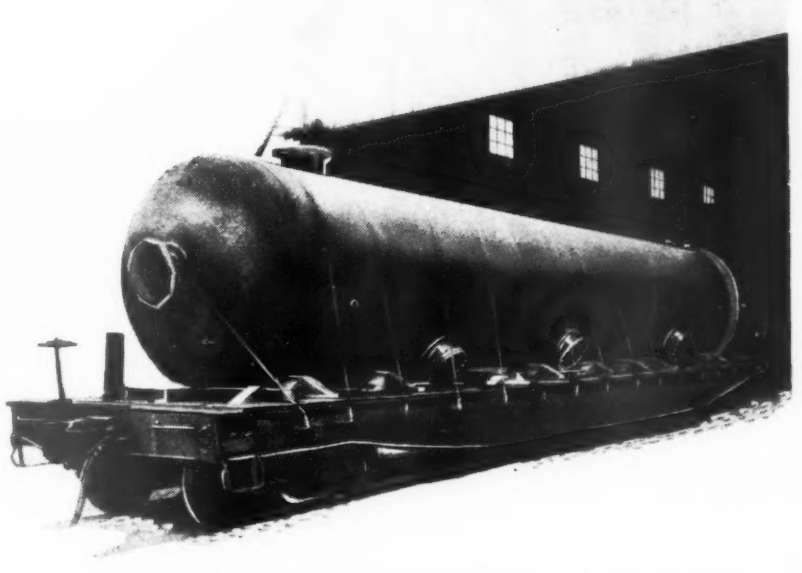

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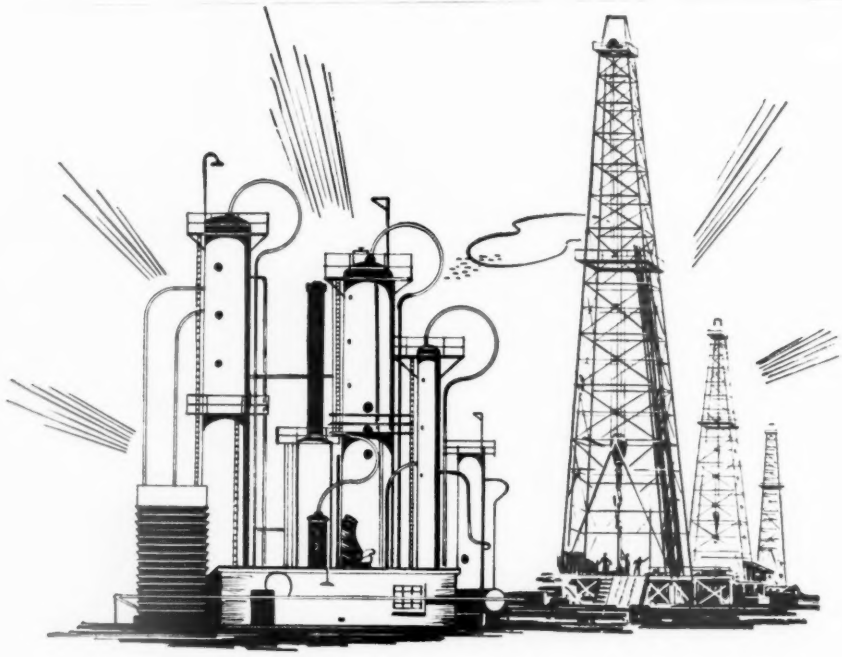

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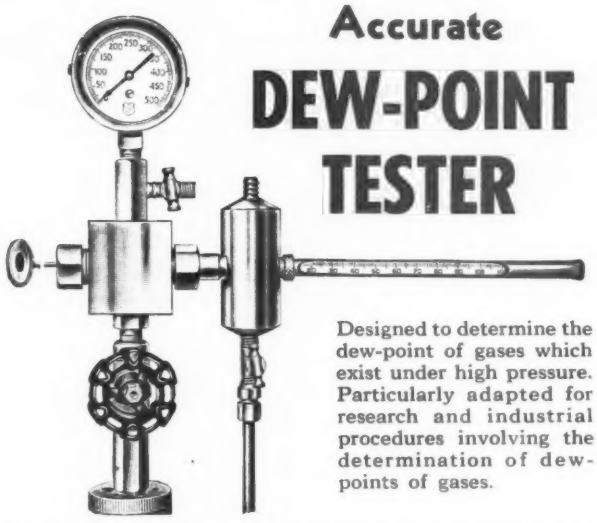

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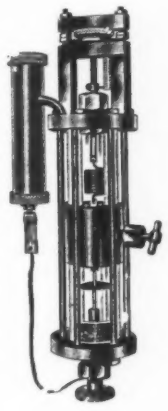

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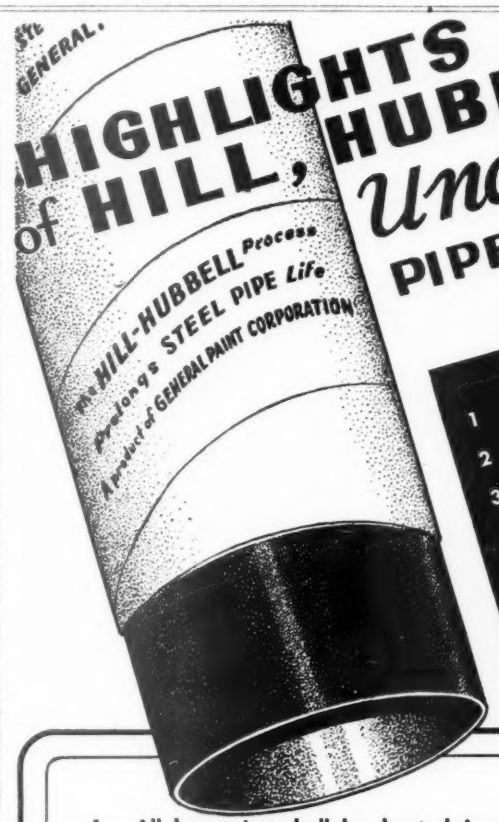

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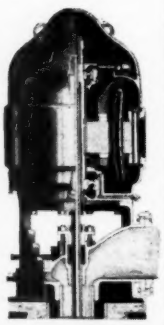

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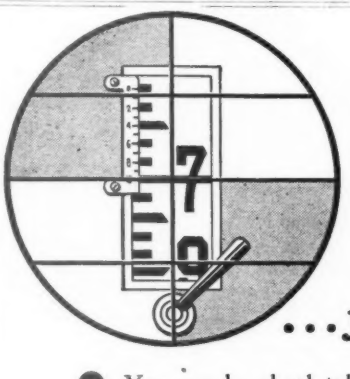

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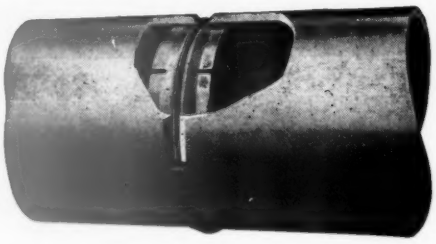

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Structural Development of Eastern Interior Basin, *J. E. Marvin Weller and L. E. Workman.*
Structural Trends and Fault Systems in Eastern Interior Basin, *Stuart K. Clark and James S. Royds.*
Subsurface Correlations of Lower Silurian Formations in Southern Illinois and Indiana, *Edward J. Combs and Ralph E. Esarey.*
Tectonics of North-Central States, *Dorsey Hager.*
Zones of Plattin-Joachim of Eastern Missouri, *John G. Grohskopf.*
Outline of Sedimentation in Maracaibo Basin, Venezuela, *H. P. Schaub,* February, 1948.
Core Orientation by Graphical and Mathematical Methods, *Hugh McClellan,* February, 1948.
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American Association of Oilwell Drilling Contractors

Long Beach, California, October 13, 1947

Producing Operations, Long Beach Harbor Oil Properties, *John R. Rumbaugh.*
Telling the Facts, *Reese H. Taylor.*
Wilmington Oil Field and the Development of City Owner Oil Lands, *Frank J. Hardesty.*

American Chemical Society

Division of Petroleum Chemistry
Chicago, Illinois, April 14-16, 1948

A Bearing Corrosion Test for Lubricating Oils and Its Correlation with Engine Performance, *E. C. Hughes, J. D. Bartelson and M. L. Sunday.*
A Semimicromethod for the Determination of Oil in Petroleum Waxes, *J. S. Wiberly and J. B. Rather, Jr.*
Alkanesulfonic Acids as Catalysts in Polymerization and Alkylation, *Wayne Proell and C. E. Adams.*
Binary Test Mixtures for the Evaluation of Vacuum Rectification Columns, *Julian Feldman, Mary Myles and Milton Orchin.*
Chemistry of Gum Formation in Cracked Gasoline, *E. L. Walters, H. B. Minor and D. L. Yabroff.*
Composition of Shale-Oil Naphtha from Colorado Shale, *John S. Ball, G. U. Dinneen, J. R. Smith, C. W. Bailey and Robin Van Meter.*
Conversion of Diolefins in Alkylation Feedstocks to Monoolefins by Selective Hydrogenation, *John Anderson, E. L. Derr and W. H. Peterson.*
Effects of Steam in the Cracking of High Sulfur Stocks with Natural Catalyst, *A. L. Conn and C. W. Brackin.*
Equilibrium and Rate Studies of the Vaporization of Liquid Hydrocarbon Mixtures Into Air, *Geo. G. Lamb and Leo J. O'Brien.*
Evaluation of Additives and Blends for Improving the Cold Starting Characteristics of Diesel Fuels, *F. L. Nelson and M. Smolak.*
Fluid Cayalyst Cracking with Silica-Magnesia Catalyst, *R. W. Richardson, F. B. Johnson and L. V. Robbins, Jr.*
Hydrocarbon Type Analysis. Estimates of Six-Membered Ring Naphthenes, *H. C. Rampton.*
Hydrocarbons from Peroleum. Composition of the C_8 Fraction of a Catalytic Gasoline by the Distex Process, *John Griswold and J. E. Walkey.*
Method of Hydrocarbon Analysis for Gas Oils and Lube Oils, *M. R. Lipkin, C. C. Martin and W. A. Hoffecker.*
Octane Number Blending Characteristics of Motor Gasoline Components, *D. P. Heath and J. S. Hicks.*
Origin of Petroleum and Natural Gas in the Light of Recent Research, *Benjamin T. Brooks.*
Polymerization of Olefins in the Presence of Dihydroxyfluoboric Acid, *J. W. Brooks.*
Pore-Size Distribution in Porous Materials. Application of the High Pressure Mercury Porosimeter to Cracking Catalysts, *L. C. Drake.*
Preparation of the C_{10} Monocyclic Aromatic Hydrocarbons, *S. F. Birch, R. A. Dean, F. A. Fidler and R. A. Lowry.*
Reaction Rate Studies on the Isomeric Hexanes, *B. L. Evering and R. C. Waugh.*
Solid Solution Studies with 2, 2, 3-Trimethylbutane. Equilibria in the Binary System 2, 2, 3-Trimethylbutane-Cychlohexane, *A. E. Hirschler, R. W. King, and W. B. M. Faulconer.*

New York City, September 15-19, 1947

Absorption Studies of a Silica Gel and a Gel-Type Catalyst, *William E. Kreger, Robert A. Van Nordstrand and Herman E. Ries, Jr.*
An Electrometric Method for the Determination of Bromine Addition Numbers, *H. D. DuBois and D. A. Skoog.*
Chemical Analysis of Refinery C_5 Hydrocarbon Fractions, *Richard F. Robey and Herbert K. Wiese.*
Determination of Asphaltenes, Oils and Resins in Asphalt, *Retbel L. Hubbard and K. E. Stanfield.*
Development of Improved Fuels for Rockets and Jet Propelled Vehicles, *Prof. Bryce L. Crawford, Robert Ginell, O. K. Rice, Clayton Huggest and John J. McBrady.*
Effects of Various Additives in the Isomerization of N-Petane, *John A. Brooks, Richard C. Wackher, Herman Pines, and Julian M. Mavity.*
Extraction of New Compounds from Petroleum to Meet Demands for Modern Industry, *Dr. Frederick D. Rossini.*
Furfural As a Selective Solvent in Petroleum Refining, *H. H. Gross, L. C. Kemp, Jr., and G. B. Hamilton.*
Gaps in Physical Constants Data for Hydrocarbons, *Mary Alexander, Nancy Corbin and Gustav Egloff.*
High-Pressure Laboratory Flow Apparatus, *L. E. Fisher, G. S. Monroe and V. N. Ipatieff.*
Investigation of Deposition and Oil Deterioration Phenomena By Means of a Motored Engine, *H. Dimond, H. C. Kennedy, and R. G. Larsen.*
Lighter Jet-Propelled Helicopter, *John B. Fenn, James W. Mullen, II, and Roland C. Garmon.*
Low-Cost Synthetic Gasoline and Oil Manufacture, *A. R. Powell, Jr.*
Mass Spectrometer-Hydrochlorination Analysis of the Butenes, *R. A. Brown and F. W. Melpolder.*
Measurement of Heat of Combustion of Volatile Hydrocarbons. A New Liquid Sample Holder for Routine or Research Measurements, *R. L. LeTourneau and Robert Matteson.*
Mercaptan Formation in Acid Treatment of Pressure Distillate, *C. R. Wilke and William James Wride.*
New Technique to Reduce Cost of Synthetic Gasoline Made from Coal, *F. Bonar, J. P. McGee, L. D. Schmidt, P. W. Edeburn, A. E. Sands and H. W. Wainwright.*
Newly Developed Technique for Gasifying Coal, *Prof. Warren K. Lewis.*
Physical Properties and Characteristics of Polyform Distillate, *H. Beuther, M. C. Fogle and W. C. Offutt.*
Production of Xylidines By High-Pressure Hydrogenation, *C. L. Brown, W. M. Smith and W. G. Scharmann.*
Production of Xylidines By High-Pressure Hydrogenation II. Quality and Performance Characteristics, *W. C. Howell, Jr., J. F. Kunc, Jr., and C. E. Starr, Jr.*
Purification, Purity and Freezing Points of N-Decane, 4-Alkylcyclopentanes, 9-Alkylcyclohexanes, 2-Monoolefins, 1, 2-Butadiene, and 2-Butyne of the API-Standard and API-NBS Series, *Anton J. Streiff, Evelyn T. Murphy, Janice C. Zimmerman, Laurel F. Soule, Vincent A. Sedlak, Charles B. William and Frederick D. Rossini.*
Reaction Between Hydrogen and Carbon Monoxide, *K. Atwood, R. E. Reitmeier, H. A. Bennett, Jr., and H. M. Baugh.*
Solutions of Aluminum Chloride in Nitroparaffins As Catalysts for Hydrocarbon Reactions, *Louis Schmerling.*
The Catalytic Addition of Paraffins to Acetylenic Hydrocarbons, *Aristid V. Grosse and Carl B. Linn.*
The Isolation and Physical Properties of the Diisopropylbenzenes, *C. E. Headington, F. W. Melpolder and J. E. Woodbridge.*
The Pyrolysis of Pentene-2 and Trimethylethylene in the Presence of Steam, *F. E. Frey and J. J. Hepp.*
The Swedish Shale Oil Industry, *Gustav Egloff.*

Technical Conference, Chicago Section
Chicago, Illinois, December 26, 1947

Petrochemicals for Agriculture, *Gustav Egloff and Mary Alexander.*

Analytical Chemistry (Analytical Edition of Industrial and Engineering Chemistry)

Analysis of Natural Gas, *Martin Shepherd,* Sept., 1947.
Aromatics In Petroleum Fractions, *C. C. Martin, M. R. Lipkin, W. A. Hoffecker and R. E. Ledley,* Feb., 1948.

Corrosion Studies In Natural Gas Condensate Wells, *D. A. Shock and Norman Hackerman*, Oct., 1947.
Determination of Antioxidants In Gasoline, *L. R. Williams and B. R. Strickland*, Sept., 1947.
Determination of Aromatics and Olefins In Hydrocarbon Mixtures, *Clyde Berg and F. D. Parker*, May, 1948.
Determination of Cyclopropane by Selective Absorption, *F. R. Brooks, R. E. Murdock, and Victor Zahn*, Jan., 1948.
Determination of Ethylacetylene and Vinylacetylene In C_4 Hydrocarbon Gases, *Leon Donn and H. C. Becker*, March, 1948.
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Determination of Olefinic Unsaturation, *G. R. Bond, Jr., E. T. Scafe and J. Herman*, Dec., 1947.
Determination of Tetraethyllead In Aviation Gasoline, *Lester Newman, J. F. Philip, and A. R. Jensen*, July, 1947.
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Estimation of Thiophene In Gasoline, *J. R. Withrow, L. K. Herndon and H. C. McKee*, April, 1948.
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New Method for Testing Catalysts, *H. R. Sheppard, Jr., and J. A. Hinckley, Jr.*, Oct., 1947.
Monographs for Distillation of Low-Boiling Hydrocarbons, *Victor Zahn, F. R. Brooks, F. M. Nelsen*, Oct., 1947.
Petroleum Solvents, *I. W. Mills and W. T. Harvey*, March, 1948.
Polarographic Determination of Naphthalenes In Petroleum Fractions, *B. E. Gordon and R. A. Burdett*, Nov., 1947.
Polymerization of Pentenes, *V. N. Ipatieff and R. E. Schaad*, Jan., 1948.
Practical Test for Estimating Storage Stability of Gasolines, *H. E. Sipple, E. L. Walters, D. L. Yabroff and H. B. Minor*, Dec., 1947.
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Raman Spectra of Hydrocarbons, *W. G. Braun, R. V. Wiegand, M. R. Fenske, Dorothy Quiggle, R. H. McCormick and D. H. Rank*, Oct., 1947.
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Technique for Measuring Reactivity of Gasoline Anti-Oxidants With Air, *B. R. Strickland*, Jan., 1948.
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Catalytic Cracking of Pure Hydrocarbons, *B. S. Greensfelder, H. H. Voge and G. M. Good*, Aug., 1947.
Selenium Dioxide As a Lubricant Additive, *Rey E. Heiks and Frank C. Croxton*, Nov., 1947.
Chemical Refining of Aromatic Hydrocarbons from Petroleum, *P. L. Brandt, R. J. Lee and F. T. Wadsworth*, Aug., 1947.
Copolymers of Butadiene With Halogenated Styrenes, *C. S. Marvel, G. E. Inskeep, Rudolph Deanin, et al*, Nov., 1947.
Copolymerization of Butadiene With Vinyl Monomers, *James R. Blegen, Robert L. Frank and Clark E. Adams*, March, 1948.
Correlation of Predicted and Observed Storage Stability of Cracked Gasoline, *H. B. Minor, E. L. Walters, and D. L. Yabroff*, March, 1948.
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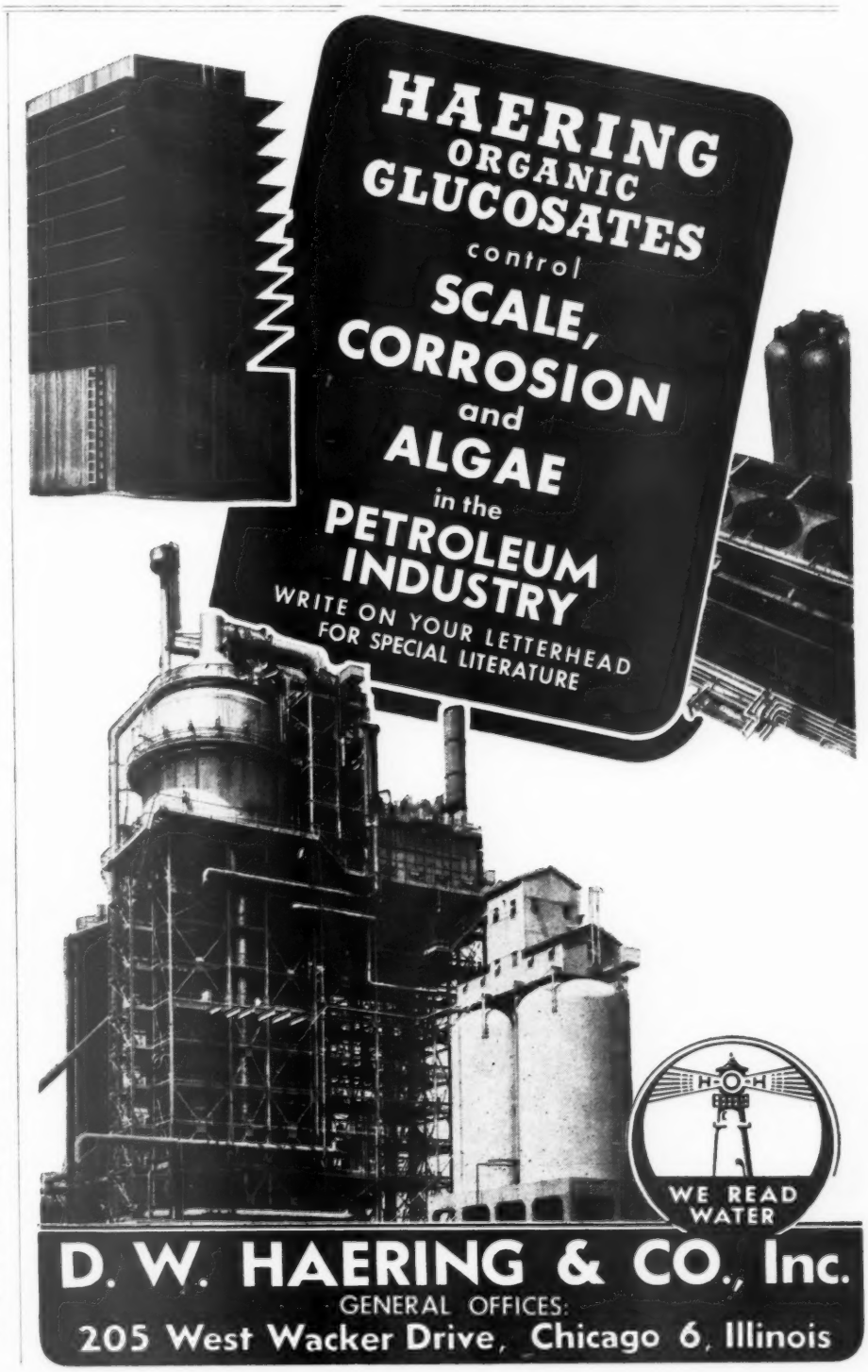
Indexing, Classifying and Coding the Chemical Literature, *James W. Perry*, March, 1948.
Isomerization of 1- and 2-Pentenes, *A. G. Oblad, J. U. Messenger and H. T. Brown*, Nov., 1947.
Large Scales Distillation of Isoprene, *Charles F. Fryling*, July, 1947.
Mean Molecular Weights of Asphalt and Their Constituents, *George W. Eckert and Bruce Weetman*, Nov., 1947.
Mechanism of Catalytic Cracking, *R. C. Hansford*, July, 1947.
Molal Refractions of Mononuclear Aromatic Hydrocarbons, *Gustav Egloff, Mary Alexander and Nancy Corbin*, Sept., 1947.
Paving Asphalt From California Crude Oil, *M. L. Kastens*, April, 1948.
Phase Relations in Heat Transfer Salt Systems, Aug., 1947.
Pilot Plants. Thermofor Catalytic Cracking Unit, *A. E. Potas, S. C. Eastwood and C. V. Hornberg*, Dec., 1947.
Pressure-Volume-Temperature Relations of Benzene, *A. N. Hixson, E. H. Amick, Jr., and E. J. Gornowski*, Oct., 1947.
Selective Demethylation of Paraffin Hydrocarbons, *Vladimir Haensel and V. N. Ipatieff*, July, 1947.
Suitability of Gasolines As Fuel, *Robert R. James and Ross E. Morris*, March, 1948.
Surface Layers on Steel in Natural Gas Condensate Wells, *Norman Hackerman and D. A. Shock*, July, 1947.
Testing of Cracking Catalysts, *M. E. Conn and G. C. Connolly*, Sept., 1947.
Vapor-Phase Chlorination of Butadiene, *G. H. Morey and Robert F. Taylor*, March, 1948.

American Institute of Mining and Metallurgical Engineers

Petroleum Division
Denver, Colorado, September 28-October 3, 1947

Application of Dipmeter Surveys, *Robert G. Hamilton and Everett F. Stratton.*
Diamond Coring At Rangely, *C. J. Christiansen.*
Drilling Mud Problems, Rocky Mountain Region, *Willard Kimbrell and D. D. Varnell.*
Drilling Problems Encountered In Church Butte Field, *J. T. Simon.*
Lance Creek Sundance Reservoir Performance Under Unitized Pressure Maintenance, *Lincoln F. Elkins, Wayne E. Glenn and R. W. French.*
Location of Water Entry Points In Various Types of Reservoirs, *A. R. Brown and Daniel Silverman.*
Mining of Oil Shale, *E. D. Gardner and Tell Ertl.*
Oil Shale Reserves, *Carl Belser.*
Our Petroleum Reserves, *Everette L. DeGolyer.*
Processing of Oil Shale, *J. D. Lankford and Boyd Guthrie.*
Refining From the Modern Point of View, *Gustav Egloff.*
Review of Geological Aspects of Exploration—Past, Present and Future—In the Rocky Mountain Region, *John Bartram.*



Uses of Electric Logging In Connection With Reservoir Engineering Problems In the Rocky Mountain Fields, *Maurice P. Tixier.*
Waters of Producing Oil and Gas Fields In Colorado, Wyoming and Montana, *J. G. Crawford.*

Tulsa, Oklahoma, October 8-10, 1947

A New Application of the Dipmeter, *Robert G. Hamilton and E. F. Stratton.*
A Note on the Calculation of Initial Distribution of Oil and Gas in Reservoirs, *Morris Muskat.*
A Turbulent Radial Flow Formula, *Jack Elenbaas and Donald L. Katz.*
An Improved Water Input Profile Instrument, *Rudolph J. Pfister.*
Analysis of Spinner Survey Results, *Robert G. Hamilton.*
Comparison of Analyzer Predictions With Actual Field Histories, *Miss Irene Haskedt.*
Displacemnt of Oil By Water and Gas, *H. J. Welge.*
Elements of Success In Engineering, *Herman H. Kaveler.*
Engineering Characteristics of the Gulf Coast Continental Shelf, *C. L. Graves and M. B. Willey.*
Important Considerations In Marine Construction, *Admiral Frederic R. Harris.*

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Location of Water Entry Points In Various Types of Reservoirs, *A. R. Brown and Daniel Silverman.*
Mechanics of Wave Action on Structures, *Walter H. Munk.*
Methane Carbon Dioxide Gas Hydrates, *Donald L. Katz and Kent.*
Methods for Estimating Gas Reserves, *Henry J. Gruy and Jack L. Critchton.*
Ocean Floor Soil Exploration and Bearing Capacity, *M. B. Willey and J. Ray McDermott.*
Overburden Pressures and Their Effect on Forces in Well Bores, *Dale Topping and A. J. Miles.*
Phase Relations of Gas Condensate Fluid at Low Temperatures, Including the Critical State, *Kenneth Eilerts, Barr, Mullens, and Hinman.*
Preplanned Programs of Directional Drilling, *Gordon Jackson and J. B. Murdoch, Jr.*
Stresses About the Bore Hole of a Deep Well, *A. J. Miles and Dale Topping.*
Water Flood and Gas Drive Experiments, *Roger Holmgren.*

Los Angeles, California, October 23-24, 1947

A Spinner-Type Surface Flow Indicator and Some of Its Practical Field Applications, *Charles M. Bryant.*
Analysis of the Results of Spinner Surveys, *a Dowell, Inc., author.*
Apparatus for Determination of the Volumetric Behavior of Fluids, *B. H. Sage and W. N. Lacey.*
California Oil Outlook, *R. L. Minckler.*
Electric Log Correlation, *Milt Loy and R. D. Ford.*
Importation of Foreign Crude to California, *a Standard of California author.*
Location of Water Entry Points in Various Types of Reservoirs, *A. R. Brown, Daniel Silverman.*
Mechanics of Wave Action on Structures, *Walter H. Munk.*
Methods of Computing Gas Reserves, *Henry J. Gruy and Jack L. Crichton.*
Methods of Determining Number of Samples Needed In Core Analysis, *Jan Law.*
Method of Predicting Pool Performance From History of Oil Production and Pressure Decline Data, *Carlton Beal.*
Preplanned Directional Drilling Programs, *John Gordon Jackson and J. B. Murdoch, Jr.*
State of Readiness of the Elk Hills Naval Reserve, *Max Eastman and Commander F. L. Ruhlman.*
Stresses About the Bore Hole of a Deep Well, *A. J. Miles and Dale Topping.*
The Limits of Uncertainty of Average Permeability and Unit Volume Estimate of Oil in Place, *Jan Law.*

American Gas Association

Annual Meeting
Cleveland, Ohio, October 16-18, 1947

Fuels for Today and Tomorrow, *Max W. Ball.*
Gas Has Got It, *John J. Quinn.*
Progress Demands Responsibility, *R. H. Hargrove.*
What About All-Year Air-Conditioning? *Frank C. Smith.*
What Natural Gas Can Do For the Manufactured Gas Industry, *Hugh H. Cuthrell.*

Spring Meeting
Houston, Texas, May 4-5, 1948

Directing Pipe Line Inspection and Maintenance, *Luther Tolbert and J. A. Martin.*
Facts on Research Progress Under the Gas Industry's Co-ordinated Program to Meet Present Peak Load Problems, *E. S. Pettyjohn.*
Flare Gas and Its Relation to Reserves, *Paul Kayser.*
Maintaining Maximum Flow Efficiency In Natural Gas Pipe Lines By Interior Cleaning, *K. D. Stephens.*
Plans and Objectives of the AGA, *Hudson W. Reed.*
Pressure Control and Other Problems of Long Line Gas Dispatching, *A. L. Bristow.*
Progress In Nationwide Natural Gas Conservation, *D. A. Hulcy.*
Progress Report of Subcommittee on Pipe Line Flow, *C. H. M. Burnham.*
Prospective Benefits From Removing Excess Nitrogen From Natural Gas, *P. V. Mullins and R. W. Wilson.*
Ten Years Under the Natural Gas Act, *William A. Doutherty.*
The Application of Centrifugal Compressors to High Pressure Gas Transmission, *B. D. Goodrich.*
The Independent Producer and the Natural Gas Business, *J. H. Dunn.*
The Royalty Owner and the Natural Gas Business, *James F. Gray.*
Tidelands Oil Case, *Price Daniel.*

American Institute of Chemical Engineers

Chemical Engineering Progress

Catalytic Dehydrogenation of Normal Butenes to Butadiene in the Presence of Steam, *L. H. Beckenberger and K. M. Watson,* March, 1948.
Catalytic Reforming, *B. S. Greensfelder, R. C. Archibald and D. L. Fuller,* Oct., 1947.
Dimensionless Groups In Fluid Friction, Heat and Material Transfer, *A. Klinkenberg and H. H. Mooy,* Jan., 1948.
Thermodynamic Properties of Ethane, *C. H. Barkelew, C. O. Hurd, J. L. Valentine,* July, 1947.
Ethylene Purification By Absorption Process, *L. Kniel and W. H. Slager,* July, 1947.
Flow of Fluids Through Porous Media—Part II—Simultaneous Flow of Two Homogeneous Phases, *L. E. Brownell and D. L. Katz,* Nov., 1947. Part III, Dec., 1947.
Fluidizing Processes, *J. D. Parent, N. Yagol, C. S. Steiner,* Aug., 1947.
Mechanism of Countercurrent Gas Liquid Flow Through Packed Towers, *F. A. Zenz,* Aug., 1947.
Rate of Approach to Equilibrium In Fractionating Columns, *C. Berg and I. J. James,* April, 1948.
Reactor Design for Manufacture of Toluene By Catalytic Reforming, *J. F. Senger, A. A. Burton, E. B. Chiswell, W. H. Claussen, and C. S. Huey,* March, 1948.
Study of Operating Variables In Thermofor Catalytic Cracking, *C. Bednars, D. M. Luntz and R. E. Bland,* April, 1948.
Vapor-Liquid Equilibria In Hydrocarbon Systems, *Stuart T. Hadden,* Nov., 1948.

American Petroleum Institute

Twenty-seventh Annual Meeting
Chicago, Illinois, November 10-13, 1947

A Bench-Scale Test Method for Evaluating Cracking Catalysts, *E. R. Birkhimer, S. J. Macuga and L. N. Leum.*
A Survey of Dual Completions, *E. B. Miller, Jr.*
Accurate Particle-Size Determination of Fluid Catalyst By Coordination of Roller Analysis and Microscopic Examination, *John T. Wiley, Joe E. Deloney and S. Walter Denton.*
Application of the Shaped-Charge Process to Petroleum Production, *Robert H. McLemore.*
Aromatic Adsorption Index for the Estimation of Surface Area and Catalytic Activity, *T. W. Pratt.*
Bench-Scale Method for Determining Activity of Cracking Catalysts In Powdered Form, *Hubert McReynolds.*
Comparison of Inventory Valuation Methods, *D. P. Jones.*
Design and Operation of a Bench-Scale Automatic Catalyst-Aging Unit, *T. Rice and T. E. Ivey, Jr.*
Determination of Activity and Selectivity of Cracking Catalyst, *Rodney V. Shankland and George E. Schmitkons.*
Economic Trends In Contract Drilling, *J. E. Warren.*
Future Problems of Transportation of Petroleum By Highway, *J. W. Sinclair.*
Gaging Method and Devices for Pressure Storage, *E. O. Mattocks.*
Gaging Methods In Atmospheric and Low-Pressure Storage, *C. C. Keane.*
High-Sulfur Crude Oils of the United States—Trends in Supply, *H. M. Smith and O. C. Blade.*
How Farm Equipment Promotes Petroleum and Progress, *Paul M. Mulliken.*
Industry's Stake in Western Europe's Recovery, *Lewis H. Brown.*
Influence of Current Replacement Costs on Corporate Earnings, *W. H. Garbade.*
Interfacial Mixing Characteristics of Products in Products Pipe Lines, *S. S. Smith, R. K. Schulze.*
"MER"—A History, *Edgar Kraus.*
Method for Cutting Into Product Pipe Lines, *James E. Ford.*
Method of Control for In-Transit and Storage Losses, *E. L. Hoffman.*
Modification in the Roller Analysis for the Determination of Particle-Size Distribution, *George L. Matheson.*
Navy Program for Petroleum-Specialist Reserve Personnel, *Capt. Ralph E. Wilson.*
Petroleum and Its Relation to National Security, *Bruce K. Brown.*
Petroleum—Industry Public Relations, *John M. Lovejoy.*
Petroleum Planning for Defense, *Maj. General T. B. Larkin.*
Pilot-Plant Evaluation of Fluid Cracking Catalysts, *H. W. Grote and C. R. Olsen.*
Pipelining in the Middle East, *Burt E. Hull.*
Planned Service Areas on Controlled-Access Roadway, *Spencer Miller, Jr.*
Plans and Purposes of the Interstate Oil Compact Commission Dealing with Secondary-Recovery Operations, *Earl Foster.*

Plans for Petroleum Personnel for the Department of Defense: Air Force, *Col. Steven C. Lombard.*
Plans for Petroleum Personnel for the Department of the Army, *Lt. Col. John D. Hines.*
Plant Control Tests for Particle-Size Distribution of Fluid Cracking Catalysts, *K. D. Ashley and W. B. Innes.*
Prediction of the Activity of Cracking Catalysts from Heat of Wetting, *Ivor W. Mills.*
President's Address, *William R. Boyd, Jr.*
Product Pipe-Line Metering Practices, *M. J. Dabney.*
Requirements of a Training Program for Petroleum Reserve Officers, *Capt. Stanley Young.*
Results of Water Injection in Woodbine Reservoir of the East Texas Field, *W. S. Morris.*
Role of the Army-Navy Petroleum Board, *Col. G. A. Vogel.*
Simplified Method for Determination of Carbonaceous Deposits on Cracking Catalysts, *F. E. Ray and A. E. Potas.*
Small-Scale Laboratory Testing of Cracking Catalysts, *G. F. Hornaday and D. B. Ardern.*
Solving Petroleum-Industry Problems, *Walter S. Hallanan.*
Sour Crudes—Equipment Protection, *E. Q. Camp.*
Standard Laboratory Method for the Determination of Cracking Catalyst Activity, *J. Alexander.*
Standardizing the Provisions of Joint-Interest Agreements, *H. H. Boyer.*
Tanker Transportation and Remarks on Inland-Waterway Operations, *M. G. Gamble.*
The Aromatic Absorption Index as a Rapid Method for Approximating Catalyst Activity, *W. W. Scheumann and A. R. Rescorla.*
The Conservation of Oil and Gas, *Hiram M. Dow.*
The Economics of Secondary Oil Recovery, W. B. Berwald.
The Formation and Operation of Cooperative Projects in Secondary Recovery, *D. V. Carter.*
The International Petroleum Situation, *B. Brewster Jennings.*
The National Transportation Survey, *John H. Frederick.*
The Petroleum Industry and the Federal Communications Commission, *Joseph E. Keller.*
The Role of Commercial Highway Transportation in American Progress, *John V. Lawrence.*
The Use of Radio in the Petroleum Industry, *F. W. Littell.*
Where Does the Sulfur Go? *M. J. Fowle and R. D. Bent.*

Eastern Division of Production,
Spring Meeting, White Sulphur Springs, W. Va.
June 30-July 2, 1948

A Report on New Gas Developments in Southern West Virginia, *E. H. Tollefson, W. W. Mayfield, and A. R. McCamey.*
Coring and Coring Methods, *Donald T. May.*
Drilling Procedure Used on Reinkardt No. 1 in Michigan, *W. E. Schoeneck.*
Liquid Petroleum Gas for Peak Loads in the Eastern District, *A. H. Lauderbaugh.*
Long Distance Transmission of Natural Gas to the Eastern District, *Edward Falck.*
Pilot Plant for Production of Synthetic Oil From Coal, *Howard S. Turner.*
Role of the Independent Gas Producer in the Eastern District, *Frank E. Eckert.*
Use of Collodial Dispersion in Water Input Wells, *J. P. Jones.*

Mid-Continent Division of Production,
Spring Meeting
Wichita, Kansas March 24-26, 1948

A Recommended Field Practice on Care and Use of Tubular Goods, *H. M. Cooley.*
An Apprentice Engineer Training Program, *Harold S. Kelly.*
Blast Cutting of Iron, *Professor W. L. Gilliland.*
Calculation of Peak Crankshaft Torque From Dynamometer Cards, *Harold S. Kelly, M. H. Halderson, P. A. Witherspoon, and E. S. Calvert.*
Classification of Plastic Coatings, *J. L. Robertson.*
Desirable Characteristics of Pumping Units and Engines, *J. C. Slonneger.*
Installing Expendable Anodes, *W. E. Huddleston.*
Magnitude of Water Flood Production in Kansas, *A. E. Sweeney.*
Performance of Water-Flooding Projects in Greenwood County, Kansas, *N. E. Maxwell.*
Practical Results of a Planned Oil-Well Corrosion Prevention Program in Western Kansas, *Walter C. Pearson.*
Statutes Relating to Secondary Recovery Operations, *R. E. Hardwicke and Walter L. Summers.*
The Significance of Hydrocarbon Synthesis in Western Kansas, *A. L. Solliday.*
Typical Projects and Problems in Secondary Recovery Operations, *D. B. Taliaferro.*
Mobile Radio Telephone Service, *Robert S. Johnson.*

Rocky Mountain Division of Production,
Spring Meeting
Casper, Wyoming, May 27-28,1948

Developments and Trends in Oil Field Producing Practices, *Jake L. Hamon.*
Employer-Employee Relations, *John R. McNulty.*
Production Problems—The Adon Block in Powder River Basin, *H. A. (Dave) True.*
Secondary Recovery in the Rocky Mountains, *C. M. Nickerson.*
Some Technical Aspects of Rotary Drilling, *John S. Schalk, Jr., and Fred M. Manning.*
The Development of Mush Creek, *J. A. Ziser.*
What Engineers Expect of Management, *Fred M. Clement.*

Lubrication Committee Meeting
Tulsa, Oklahoma, April 28, 1948

Activities and Objectives of the Lubrication Committee, Division of Marketing, API, *J. M. Koch.*
A.S.M.E. Activities in Lubricants and Lubrication, *Paul G. Exline.*
Objectives of the American Society of Lubrication Engineers, *O. L. Maag.*
Supply and Demand for Lubricants — United States Years 1918-1947 and Forecast Through 1951, *A. J. McIntosh.*
The Activities of the American Society for Testing Materials in the Field of Lubricants and Lubrication, *L. C. Beard, Jr.*
The Armed Services' Present and Future Lubricant Requirements, *Col. G. H. Vogel.*

Division of Refining Mid-Year Meeting
Philadelphia, Pennsylvania, May 10-15, 1948

A Resumé of Sohio's Experience in Overhead Condensing Equipment, *E. N. Salathe.*
Determining Refinery Training Needs, *A. H. Houseknecht.*
Experiences in Establishing Organized Training Practices, *W. J. McClintock.*
Front End Volatility As It Affects Processing of High Octane Number Fuels, *L. L. Davis.*
Natural-Gas Butane and Motor-Fuel Vapor Pressure, *R. C. Alden and T. W. Legatski.*
Preliminary Report on Training Practices in the Refineries of the United States, *James R. D. Eddy.*
Prevention of Corrosion in Refinery Heat-Exchanger Equipment, *M. A. Furth.*
Problems in the Efficient Utilization of Refinery Butanes, *T. L. Apjohn and D. P. Heath.*
Refinery Tools for Producing High Octane Gasoline, *T. B. Kimball and J. A. Scott.*
Selection of Valve Materials for Petroleum Application, *H. O. Teeple.*
The Butane Problem as Viewed by an Integrated Refiner, *H. R. Poland.*
The Factor of Gasoline Tail End Volatility, *J. Bennett Hill and Walter C. Huffman.*
The Role of Paint in Combatting Corrosion in the Petroleum Industry, *Paul L. Lotz.*
The Use of Chemicals for Retarding Corrosion, *H. L. Bedell.*
Tomorrow's Oil, *James Terry Duce.*
Training of Process Operators, *Charles P. Baker and H. A. Lutz.*

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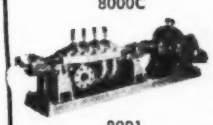
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Pacific Coast Division of Production, Spring Meeting
Los Angeles, California, May 6-7, 1948

A Subsurface Flow Rate Indicator and Its Application, *F. M. Carlisle.*
Achievement of Mobility in Drilling Units, *W. F. Bates and J. N. Gregory.*
Advancements in Contract Drilling, *A. J. Heiser.*
Application of Hydraulic and Pneumatic Devices to Drilling Equipment, *N. A. D'Arcy, Jr.*
Application of Secondary Recovery in the United States As Related to Emergency Oil Requirements, *Paul D. Torrey.*
Economics of Cycling, *M. G. Arthur.*
Field Results of Jet Perforator Charges, *Robert T. Harcus.*
Measurement of Mud Viscosities at High Temperatures, *V. N. Bednarski.*
Middle East, *Harold F. Sheets.*
Progress of API Standards, *H. N. Marsh.*
Recent Diamond Coring in California, *W. C. Harrington and M. C. Eastman.*
Some Limitations of Rod Pumping, *K. T. McCammon.*
The Oil Industry and Politics, *A. C. Mattei.*
The Prediction of Oil Recovery by Water Flood, *R. L. Parsons and Herman Dykstra.*

Southwestern Division of Production, Spring Meeting
San Antonio, Texas, April 14-16, 1948

A New Type of Porosimeter, *Emil Kaye and M. L. Freeman, Jr.*
Analysis of Unconsolidated or Loosely Consolidated Core Samples, *S. H. Rockwood.*
Artificial Lift in the Permian Basin (in two parts): Part I—Hydraulic Pumping in West Texas, *E. B. Armstrong Part II*—Gas Lift Methods in West Texas, *J. B. Harrell, Jr.*
Drill Pipe Failures, Inspection and Protection in the Permian Basin, *W. H. Crenshaw, V. B. Bottoms, C. N. Wallace, and C. R. O'Dell.*
Gas Repressuring in Texas, *Roland Gouldy.*
Industrial Relations, *Capt. A. A. Nicboson.*
Interstate Oil Compact Commission, *Gov. Beauford H. Jester.*
Offshore Drilling Development, *D. A. McGee, A. T. F. Seale, and G. O. Danielson.*
Organized Fighting of Fires and Blowouts, *Jack Kinley and C. P. Parsons.*
Our Changing World, *Geo. S. Benson.*
The Relation of Nozzle Fluid Velocity to Rate of Penetration with Drag Type Rotary Bits, *J. P. Nolley, George F. Cannon and Douglas Ragland.*

Production Division, Spring Meeting
Yellowstone National Park, Wyoming, June 25, 1947

Secondary Recovery in the Rocky Mountain Region, *Nat A. Slagter.*
Unit Operations, *J. F. Cullen.*

Marketing Division, Atlantic City, New Jersey
May 6-7, 1948

Eliminating Profit Leaks in Oil Marketing, *Russel S. Williams.*
Looking Ahead With the Petroleum Industry, *Max W. Ball.*

American Society of Mechanical Engineers

Annual Meeting, Atlantic City, New Jersey, December 1-5, 1947

An Analysis of the Full-Floating Journal Bearing, *M. C. Shaw and T. J. Nussdorfer, Jr.*
Analysis of Tests on Positive Displacement Meters for Liquid Hydrocarbons, *E. E. Ambrosius.*
Asphalt in the Building Industry, *R. Brown.*
High Pressure Gas Measurement, *E. E. Stovall.*
High Temperature Performance of Silicone Fluids in Journal Bearings, *J. E. Brophy, John Larson, and R. O. Militz.*
Practical Lubrication Engineering, *David A. Hall and W. T. Everett.*
Problems Associated with the Use of Diesel Fuels, *W. L. H. Doyle and E. W. Landen.*
Synthetic Liquid Fuels in the United States, *W. C. Schroeder.*
Measurements of the Combined Frictional and Thermal Behavior in Journal Bearing Lubrication, *S. A. McKee, H. S. White, and J. F. Swindells.*
The Removal of Aldehydes From Diesel Exhaust Gas, *Rogers F. Davis and M. A. Elliott.*

Houston, Texas, October 5-8, 1947

Application of Internal Combustion Engine Power to Rotary Drilling Rigs, *W. S. Crake.*
Accessories for Good Operation of Pressure Storage Vessels, *Fred L. Goldsby.*
Comparison of Prime Movers for Pumping Wells, *J. H. Field.*
Corrosion of Oil Well Equipment, *L. C. Case.*
Control of Comingling in Products Pipe Lines, *E. A. Birge.*
Effect of Leakage Around Cross-Baffles in a Heat-Exchanger, *A. M. Whistler.*
Heavy Crude Oil and Fuel Oil Handling, *E. L. Adams.*
Hydraulic Pumpers for Shallow Wells, *A. A. Hardy.*
Hydraulic Pumping of Oil Wells—a Progress Survey, *W. F. Slater.*
Interfacial Mixing Characteristics of Products in Product Pipe Lines, *R. K. Schultze and S. S. Smith.*
Internally Insulated Piping and Pressure Vessels for High Temperature Service, *P. E. Darling.*
Investigation of Stress in Vessels Under Internal Pressure, *T. L. White.*
Notes on Natural Gas Transmission, *W. H. Stueve.*
Properties of Low Carbon 8½% Nickel Steel, *T. N. Armstrong and G. R. Brophy.*
Service Life of Austenitic Alloy Furnace Tubes, *Charles S. Pugsley, Jr.*
Some Factors Influencing Comingling in a Products Pipe Line, *D. A. Roach.*
Some Factors Influencing Selection of Factors of Safety in Casing Design, *E. N. Kemler.*
Sufsurface Sucker Rod and Gas Lift Pumps, *R. L. Chenault.*
The Application of New Designs in Plunger Pumps With Some Comments on the Handling of Viscous Crudes, *T. R. Aude and L. T. Gibbs.*
The Manufacture and Application of Composite Plates, *O. R. Carpenter.*
Welding Thick Aluminum for Low Temperature Service, *C. B. Voldrich.*

Spring Meeting, New Orleans, Louisiana
March 1-4, 1948

A Mathematical Analysis of a Number of Dielectric Heating Problems, *M. P. Heisler.*
Accurate Wide Range Metering of Natural Gas With the Differential Type Meter, *L. K. Spink.*
Carry-Over Improvement on a High Pressure Boiler at Baytown Refinery, *H. B. Snider and F. H. Ward.*
Conversion of the "Big Inch" and "Little Big Inch" Pipelines From Oil Service to Gas Transmission, *B. D. Goodrich.*
Design and Operational Features of the Industrial Canal Steam-Electric Station, *A. H. Jensen and J. F. Vogt, Jr.*
Developments in Kraft-Process Recovery-Unit Design and Performance, *R. K. Allen.*
Gas Turbine Power Plants for Operation With Low Cost Fuel, *John Goldsbury.*
Heat Transfer Analysis of a Multi-Component Structure by Comparative Methods, *C. F. Kayan.*
Progress of A.S.M.E. in Region VIII, *Linn Helander.*
Survey—How New Gas Turbines Fit Into Tomorrow's Power Pattern, *S. A. Tucker.*
The Engineer and Internationalism, *E. G. Bailey.*
The Gas Turbine as Stationary Prime Mover, *L. N. Rowley, Jr., and B. G. Skrotski.*
The Performance of Commercial Gas Turbines, *Paul R. Sidler.*
Why Good Government Is Related to Good Engineering and Good Business, *Hon. DeLesseps S. Morrison.*

Spring Meeting, Tulsa, Oklahoma, 1947

Deep-Well Camera, *O. E. Barstow and C. M. Bryant.*
Petroleum Pumper Acitivities, *H. G. Thuesen.*

Chicago Technical Conference

Chicago, Illinois, March 22-24, 1948

Future Liquid Fuels, *F. C. Gunness.*
Modern Trends in Fuels and Lubricants, *W. J. Backoff.*

Commercial Chemical Development Association

New York City, March 20, 1948

An Investment Manager Looks at the Chemical Industry, *Ragner D. Naess.*
Gearing Commercial Chemical Development to Manufacturing, *John J. Healy, Jr.*
Gearing Commercial Chemical Development to Research, *Dr. C. F. Rassweiler.*
Gearing Commercial Chemical Development to Sales, *D. K. Ballman.*
Management's Appraisal of Commercial Chemical Development, *Dr. Westbrook Steele.*
The Job Facing the Chemical Industry, *William P. Marsh.*
The Role of the Investment Banker and Investment Trust in Financing the Chemical Industry, *Henry C. Breck.*

Independent Natural Gas Association

Annual Membership Meeting
Oklahoma City, October 24, 1947

A Royalty Owner Looks at the Gas Industry, *James F. Gray.*
Current Legal Problems of the Natural Gas Industry, *Glenn W. Clark.*
Gas for Tomorrow, *Gail F. Moulton.*
Some Operating Problems of the Independent Producer, *L. T. Potter.*
Synthetic Liquid Fuels and Chemicals From Natural Gas, *George Roberts, Jr.*
The California Line—Economic and Physical Problems, *Paul Kayser.*
The Problems of the Distributing Company as Related to Producers and Transporters, *R. G. Taber.*

Independent Petroleum Association of America

Annual Meeting, Oklahoma City, Oklahoma
September 27-30, 1947

Importance of the Trade Association in Industry, *James L. Donnelly.*
Objectives and Activities of the Foundation of Applied Research, *Raymond L. Neumann.*
The Challenge to the Domestic Industry to Meet Current and Future Oil Demand, *Rush M. Blodget.*
Unitization and Secondary Recovery, *R. I. Williams.*

Mid-Year Meeting
Wichita Kansas, April 26, 1948

A Few Kind Words for the Root of All Evil, *Ralph C. Champlin.*
April, 1948, Quarterly Report of the Supply and Demand Committee of the IPAA.
Current IPAA Public Relations Program, *Frank B. Taylor.*
N.P.C. Steel Survey Poses Important Policy Questions, *Minor S. Jameson, Jr.*
Petroleum, the Industry—Black Gold Not Blackguard, *John W. Boatwright.*
Proposed Public Relations Program (a Report), *Curtis F. Bryan.*
Report of the General Counsel, *Russell B. Brown.*
Some Practical Problems for Secondary Recovery Research, *Richard V. Hughes.*
The Oil Industry and the Oil Writers, *U. S. Congreesman H. A. Meyer.*

Institute of Petroleum

Publications in Journal

A New Method for the Presentation of Test Results on the Four Ball Machine, *W. Davey,* Sept., 1947.
Aluminum Stearate Gels for Use as Flame-Thrower Fuels, *C. M. Cawley, J. H. G. Carlile, J. G. King, and F. E. T. Kingman,* Dec., 1947.
Aluminum Stearate Gels in Light Hydrocarbon Oils, *C. M. Cawley, J. H. G. Carlile, J. G. King, and F. E. T. Kingman,* Nov., 1947.
Aromatics From Petroleum, *H. Steiner,* July, 1947.
Automatic Control of Refinery Operations, *W. S. Ault,* Oct., 1947.
Examination of Used Engine Lubricating Oils, *K. Hilfreich, J. C. McNicol, and L. Rosenfeld,* March, 1948.
Development of Hydrogenation and Fischer-Tropsch Processes in Germany, *K. Gordon,* Aug., 1947.
Experiments on the Rate of Foam Application to Petrol Fires, *J. A. Lewis, N. O. Clark, and E. Thornton,* March, 1947.
Explosive Decomposition of Ethene, *H. I. Waterman, W. J. Hessels, Jr., and J. van Steenis,* April, 1947.
Fires and Explosions at Oil Installations, *E. P. Lancashire,* March, 1947.
Fires in Open Tanks of Petroleum Products: Some Fundamental Aspects, *J. H. Burgoyne and L. L. Katan,* March, 1947.
Fuels and Lubricants for Aero Gas Turbines, *C. G. Williams,* May, 1947.
Hydrocarbon Synthesis in the Presence of Cobalt Catalysts at Medium Pressures, *S. L. Smith and C. C. Hall,* July, 1947.
Improved Method for the Interpretation of Experimental Data Obtained in Molecular Weight Determinations of Petroleum Fractions, *J. G. Reynolds,* Aug., 1947.
Incendiary Fuels for Various Purposes, *C. M. Cawley, J. H. G. Carlile, J. G. King, and F. E. T. Kingman,* Feb., 1948.
Liquid Fuels and Chemical Products From Petroleum and Coal, *F. H. Garner,* Nov., 1947.
Lubricating Oil Testing in Engines, *J. C. Cree and R. Stansfield,* April, 1948.
Metallurgical Methods for Combating Corrosion and Abrasion in the Petroleum Industry, *B. B. Morton,* Jan., 1948.
Modern Developments in Geophysical Prospecting, *Ir. A. Van Weelden,* June, 1947.
Naphthenic Acids: Boiling Points and Distribution in Gas Oil Distillates, *K. F. Coles,* May, 1947.
Petroleum Products in Agriculture: The Role of Petroleum in Plant Protection, *L. W. Leyland Cole,* April, 1947.
Petroleum Products in the Printing Ink and Allied Industries, *L. Ivanovszky and A. C. Healey,* Sept., 1947.
Reference Fuels for Knock Rating in Spark Ignition Engines, Sept., 1947.
Refining South American Crudes, *D. Read and G. Egloff,* Oct., 1947.
Rheological Investigation of Asphaltic Bitumen in Connexion With Its Technical Applications, *R. N. J. Saal,* Feb. ,1948.
Second Report on Tests for Soil Stabilization, *Soil Stabilization Panel of Standardization Sub-Committee No. 7, Asphaltic Bitumen,* Feb., 1947.
Simple Chemical Analysis of Isobutene in Binary Mixtures with Other Olefins, *J. P. W. Houtman,* April, 1948.
Solvent Extraction of Indene and Coumarone From Coal Tar Light Oils, *J. N. Breston and A. W. Gauger,* Nov., 1947.
Some New Extreme Pressure (E.P.) Lubricating Oil Additives Containing Chlorine and Sulphur, *W. Davey,* Aug., 1947.
Spectroscopic Analysis: Application of the Hydrogen Discharge Lamp to the Analysis of Mixtures of C8 Aromatic Hydrocarbons, *R. R. Gordon, H. Powell, and J. Tadayyon,* Feb., 1947.
Substitution and Polymerization Reactions of Thiophen and the Isomeric Thiophthens, *Joseph Bruce, Frederick Challenger, Harry B. Gibson, and Wilfrid E. Allenby,* March, 1948.
Tank Calibration, *Tank Calibration Panel,* April, 1948.
The Alkylation of isoParaffins with Olefins in the Presence of Sulphuric Acid. Part I. The Composition of an Aviation Alkylate, *Alan R. Richards and Frank Morton,* Dec., 1947.

The Alkylation of isoParaffines With Olefins in the Presence of Sulphuric Acid. Part II. The Action of Sulphuric Acid on the Trimethylpentanes, *A. R. Richards and F. Morton*, Feb., 1948.
The Application of a New Notation to Petroleum Hydrocarbons, *G. Malcolm Dyson*, June, 1947.
The Application of the Principles of Clay Chemistry to Problems Encountered When Drilling in Trinidad Clays, *H. C. H. Darley*, April, 1947.
The Chemical Aspects of the Petroleum Acts, *S. G. Burgess*, June, 1947.
The Crude Oil of England, *J. S. Parker*, April, 1947.
The Effect of Sulphur and Phosphorus on Aviation Fuel Performance, *T. K. Hanson and K. F. Coles*, Oct., 1947.
The Extreme Pressure (E.P.) Lubricating Properties of Some Bromine and Iodine Compounds, Alone and in Presence of Sulphur, With Observations on the Mechanism of the Development of E. P. Properties, *W. Davey*, Nov., 1947.
The Fluid Solids Technique: Applications in the Petroleum Industry, *E. V. Murphree, E. J. Gohr, and A. F. Kaulakis*, Oct., 1947.
The Institute of Petroleum Hydrocarbon Research Group: Review of Progress, 1945 to 1947, Sept., 1947.
The Lubrication of Pre-Selective Gear-Boxes, *A. T. Wilford*, Jan., 1947.
The Oil Shale Deposits of the World and Recent Developments in their Exploitation and Utilization, Reviewed to May, 1947, *W. H. Cadman*, Feb., 1948.
The Oxidation of Transformer Oil, *J. J. Lock, P. M. Heertjes, C. D. Ten Have, Sept.*, 1947.
The Oxygen Boost Method of Rating the Engine Performance of Aviation Fuels, *R. C. Morris, W. B. Heaton, T. K. Hanson*, April, 1947.
The Structure and Properties of Ethylene Polymers, *R. B. Richards*, April, 1948.
The Ten Dimethylnaphthalenes, Their Physical Properties, Molecular Compounds, and Ultraviolet Spectra, *J. C. Smith, A. S. Bailey, K. C. Bryant, R. A. Hancock, and S. H. Morrell*, Aug., 1947.
The Vaporization of Fuels for Gas Turbines. Part II. Heat Quantities Required to Vaporize Gas Turbine Fuels, *B. P. Mullins*, Jan., 1947.
Viscometry of Soap-in-Hydrocarbon Systems, *G. F. Wood, A. H. Nissan, and F. H. Garner*, Feb., 1947.

International Congress of Pure and Applied Chemistry

London, England, July 17-24, 1947

Commercial Application of Catalytic Polymerization, *Gustav Egloff and P. C. Weinert.*
Chemical Interdependance of Agriculture and Petroleum.

Instrument Society of America

Annual Conference and Exhibit
Chicago, Illinois, September 8-12, 1947

Adaptation of the Automatic Spectrophotometer for Special Measurements, *R. H. Kienle and E. I. Stearns.*
Applications of Viscosity Measurements in Petroleum Refining Operations, *D. J. Pompeo.*
Instrument Installation and Maintenance Methods and Practices in a Modern Oil Refinery, *G. A. Larsen.*

Interstate Oil Compact Commission

Spring Meeting, Chicago, Illinois
May 6-7, 1948

Interstate Oil Compact Commission Economics Advisory Committee Report No. 7.
Nationalization—Panacea or Pandemic, *Governor Beauford H. Jester.*
Would Our Petroleum Problems Best Be Solved Under Federal or State Regulation, *B. A. Hardey.*

Mid-Continent Oil and Gas Association

Annual Ad Valorem Tax Forum
Jackson, Mississippi, December 15-16, 1947

Ad Valorem Assessment and Taxation in Illinois, *J. D. Howie.*
Ad Valorem Tax Trends in Oklahoma, *Ford C. Harper.*
History and Trends of Taxation Ideas, *M. M. Hargrove.*
Tax and School Trends in Kansas, *Alex Hotchkiss.*
The Mississippi Tax System, *A. H. Stone.*
The Need for an Analysis of the Louisiana Tax Structure in Order to Insure a Balanced Tax Program, *Cecil Morgan.*
The Tax Picture in Arkansas, *W. H. Rector.*
The Taxpayer's Blind Side, *Dr. Roy E. Brown*
There Are Many Taxes But Only One Source of Revenue—the Taxpayer, *C. A. Jay.*
Trends in Educational Costs, *Lee Johnson.*
Welcome to Mississippi, *Fielding L. Wright.*

Midwest Power Conference

Annual Meeting
Chicago, Illinois, April 7-9, 1948

A New Appraisal of the Fuel Situation, *John Van Brunt.*
A Simplified Panel Heating Design Procedure, *B. F. Raber and F. W. Hutchinson.*
A Test Cell for Measuring Engine Noise, *W. P. Green.*
Application of Heat Balance Analysis to Industrial Plants, *H. C. Carroll.*
Application of oil Reclosers on Distribution Systems, *R. O. Askey and C. V. Miller.*
Causes and Prevention of Condensate-Return-Line Corrosion, *R. T. Hanlon.*
Circuit Principles of Industrial Electronic Control, *Walther Richter.*
Combustion in Diesel Engines, *Otto Uyehara and P. S. Myers.*
Comparative Performance of Panel and Convection Systems in Research Residence, *S. Konzo and R. W. Roose.*
Condensers, Their Use and Application in Water-Shortage Areas, *R. J. Martin.*
D. C. High Power Distribution Systems, Short Circuit Analysis, *William Deans.*
Development of Requirements of Copper Wire Connections, *Frank E. Sanford.*
Electrical Measurement of Nonelectrical Quantities, *Everett S. Lee.*
Electronically Controlled Motor Drives, *Marvin M. Morack.*
Estimates of Future Electric-Power Needs of the United States, *F. R. Benedict.*
Excitation Requirements and Control of Reactive Power, *W. A. Lewis.*
Experiences With a Multiple Fuel-Fired Water-Tube Boiler, *R. Frank Hollis.*
Experiment on Underground Gasification in the United States, *W. C. Schroeder.*
Furnace Design Methods, With or Without Water Walls, *Ollison Craig.*
Measurement of Power and Power Factor in Industrial Plants, *Erwin Boland.*
Operation and Test Experience With an Experimental 2000-hp Gas Turbine, *T. J. Putz.*
Opportunities in the Power Field, *A. C. Montieth.*
Power System Stability, *E. W. Kimbark.*
Progress Report on the Coal-Burning Gas Turbine, *J. I. Yellott and C. F. Kottcamp.*
Recent Developments in Boiler Water Research, *F. G. Straub.*
Rectifier Power Supplies for D-C Systems, *C. R. Marcum.*
Research and Social Progress, *Charles E. Friley.*
Rotating Regulator Excitors, *C. Lynn.*
Selection of Mechanical Draft Fans, *A. P. Darlington.*
Steam Power Plant Appraisal, *Harry F. Lowe.*
Supervisory Control, *A. P. Peterson.*
Synthetic Rubbers and Resins as Insulation for Wires and Cables, *J. T. Blake.*
Telemetering Channels, *R. J. Donaldson.*
Telemetering of Power, Reactive Power, and Similar Quantities, *Nathan Cohn.*
The Foreign Power Situation, *Walker L. Cisler.*
The Practical Approach to Modern Boiler Water Treatment, *R. C. Ulmer.*
Use of High Alkalinity and Organic Materials for Sludge Removal in H-P Boilers, *Selden K. Adkins.*
Why So Many Gas Turbine Cycles? *L. N. Rowley and B. G. A. Skrotzki.*

Natural Gasoline Association of America

Annual Convention
Fort Worth, Texas, March 24-26, 1948

A Study of Cycling Operations in the West Austin Sand, *Charles B. Johnson, Jr.*
Application of Superexpansibility Factors in High Pressure Gas Measurement, *E. P. Valby.*
Condensation of Hydrocarbon-Water Mixtures in Fin-Wall Tubes, *Dr. D. L. Katz.*
Curing Corrosion in Gas-Condensate Wells, *T. S. Bacon.*
Developments in the Natural Gasoline Industry, *George A. Burrell.*
Economics of Anti-Detonant Injection, *C. H. Van Hartesveldt.*
Engines and Fuels for Higher Efficiency, *J. M. Campbell and L. L. Withrow.*
Inflammability of Gases, *G. M. Kintz.*
Maximum Recovery of Hydrocarbons, *W. J. Murray.*
Modern Process Methods to Improve Light Ends Recovery, *G. W. McCullough, K. H. Hackmuth and A. J. Miller.*
More Propane for Less Money, *Z. C. Ambrose.*
Risk Capital in the Petroleum Industry, *Richard Wagner.*
Significance of Liquids From Natural Gas, *C. R. Williams.*
The Oil Industry Today, *R. M. Chan.*

Gulf Coast Regional Meeting
Corpus Christi, Texas, January 30, 1948

Engine Maintenance, *Ralph Boyer.*
Fundamentals of Fractionation, *A. J. L. Hutchinson.*
Gas Synthesis on the Gulf Coast, *P. C. Keith.*
Hydrocarbons—What Are They? *Dr. Frank Dotterweich.*
Inflammability of Gases, *G. M. Kintz.*
Organization of Plant Safety Program, *R. C. Burrow.*
Trading Information, *C. R. Williams.*

Panhandle Plains Regional Meeting
Amarillo, Texas, December 12, 1947

Carbon Black in the Texas Panhandle, *Ira Williams.*
Changing Times in the Natural Gas and Gasoline Industry, *L. R. Hagy.*

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Keeping Posted, *C. R. Williams.*
Maintenance and Operation of Plug Valves, *Roy Bush.*
Plant Operations for Maximum Recovery of LPG, *J. A. Craig.*
Progress of the Panhandle Gas Field, *Col. E. O. Thompson.*
Water Treatment for Gasoline Plants, *J. C. Hutcheson.*

National Association of Corrosion Engineers

Conference and Exhibition
St. Louis, Missouri, April 5-8, 1948

Action of Rust-Preventive Oils, *E. R. Barnum, R. G. Larsen, and A. Wachter.*
Analysis of NACE Condensate Well Corrosion Field Data, *V. V. Kendall.*
Cathodic Protection in Gas Distribution Systems, *F. B. Fry.*
Cathodic Protection of Casings in Loudon Pool, *S. P. Ewing and J. F. Bayhi.*
Corrosion Problems in a Modern Fluid Catalytic Cracking and Fractionating Unit, by *Nathan Schofer.*
Corrosion Problems in Water Wells, *T. E. Larsen.*
Effects of Hydrogen Generated by Corrosion of Steel, *M. H. Bartz and C. E. Rawlins.*
Fifteen Years' Experience in Application of External Corrosion Mitigation Methods to a High Pressure Natural Gas Transmission Line, *N. K. Senatoroff.*
Laboratory Determination of the Relative Corrosion Resistance of Metals Considered for Condensate Well Service, *C. K. Eilerts, Faye Greene, F. G. Archer, and L. M. Burman.*
Present-Day Aspects of Condensate Well Corrosion, *H. E. Waldrip.*
Reference Electrodes: Design and Polarization Characteristics, *R. F. Hadley, F. A. Young, and D. F. Van de Water.*
Sour Crudes-Equipment Protection, *E. Q. Camp.*
The Cathodic Protection of Steel in Sea Water Using Magnesium Anodes, *H. A. Humble.*
Twenty Years of Cathodic Protection in New Orleans, *R. J. Kuhn.*

National Lubricating Grease Institute

Annual Meeting
Chicago, Illinois, October 16-18, 1947

Atomic Energy, *H. D. Hass.*
Modernization of Grease Manufacturing, *Claude Johnson.*
Research—the Third Dimension, *Harold Vagtborg.*
The Grease Phase of Steel Plant Lubrication, *C. E. Pritchard.*

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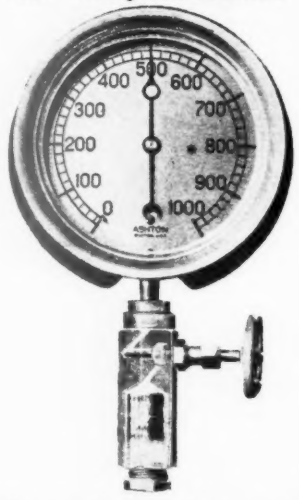

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National Petroleum Association

Atlantic City, New Jersey, September 17-19, 1947

An Analysis of the Railroads' Case for Another Rate Increase, *Harry S. Elkins.*
Freedom Is What You Make It, *Robert T. Haslam.*
Gas Oil Polyforming, *W. C. Offutt, M. C. Fogle, Paul Ostergaard, and H. Beuther.*
Lubrication Committee A.P.I.—Its Organization and Objectives, *D. P. Clark.*
New Aspects of Pour Depressant Treated Oils, *C. E. Hodges.*
Oil's Open Door, *Robert G. Dunlop.*
The Economic Future of Europe, *Jas. A. Perkins.*
The Post War Economy and the Oil Industry, *Alexander Sachs.*
Trends in Motor Fuels, *H. R. Wolf.*

Semi-Annual Meeting
Cleveland, Ohio, April 21-23, 1948

Development of Pension and Insurance Plans, *H. Charles Kwasha.*
Inhibitor Action in Crankcase Oils, *Dr. Carl F. Pruttan.*
Motor Fuel Trends, *W. M. Holaday.*
Panel Discussion on Petroleum Demand and Supply, 1948 and 1949—
Military Petroleum Requirements, *Col. G. H. Vogel;*
Railroad Diesel Engines, *W. W. Kelly;*
Tractors and Engine-Operated Farm Equipment, *K. W. Anderson;*
Central Oil Heating Units, *Robert Gray;*
Space Heaters, *Carl R. Jonswold.*
Passenger Automobiles, *Russell E. Singer;*
Petroleum Supply, *A. J. McIntosh.*
Recent Marketing Experience and a Look Into the Future, *B. L. Majewski.*
Review of Current A.T.S.M. Activities, *H. P. Ferguson.*
Tariff Problems—Railroad and Pipe Line, *E. W Chapdelaine.*

National Safety Council

The Safety Program—a Unique Management Tool, *H. H. Anderson.*
Training Methods in the Petroleum Industry, *Sterling W. Mudge.*

North Texas Oil and Gas Association

Annual Meeting
Wichita Falls, Texas, March 6, 1948

Causes and Costs of Industrial Accidents in Texas, *A. F. Allen.*
Economic Aspect of Water Flood Projects in North Texas, *Walter C. Krog.*
Forecasting the Costs of Drilling, *W. K. Powell.*
Gas Repressuring in North Texas, *Roland Gouldy and Gordon R. Stine.*
Legal Aspects of Voluntary Unitization and Cooperation Agreements, *R. M. Wagstaff.*
Relationship of the Drilling Contractor to the Petroleum Industry—the Tubular Goods Situation, *J. Ed. Warren.*
Secondary Recovery Research in Texas, *Wm. J. Murray, Jr.*
Survey of Water Flood Operations in North Texas, *R. K. Guthrie.*
Theft Prevention, *John Kelley.*
The Significance of Connate Water, Capillary Pressure and Relative Permeability in Secondary Recovery, *Dr. Geo. H. Fancher.*
The Tax Outlook for 1948, *A. D. Nelson.*
Wage-Hour Law and Its Application to the Petroleum Industry, *W. J. Rogers.*
We've Got a Story, *Paul Cain.*

Oklahoma Utilities Association

Annual Meeting
Oklahoma City, Oklahoma, March 11-12, 1948

Air Industrial Preparedness, *Rush Gibbs.*
Defrosting America's Frozen Assets, *James D. Arrington.*
Discussion of Oil and Gas Industry, *Claude V. Barrows.*
In General, *R. K. Lane.*
Legislative Council, *Hon. James C. Nance.*
Something to Think About, *D. S. Kennedy.*
Sources and Values of American Liberty, *J. P. Battenberg.*
Straws in the Economic Winds, *Arthur A. Smith.*

Gas Division
Oklahoma City, Oklahoma, September 19, 1947

Building a Commercial Load, *L. J. Fretwell.*
Discovery and Control of Leakage in Town Plants, *H. D. Portwood.*
Gas Man's Civic Obligation, *W. D. Little.*
Pressure Regulation on Town Plant Distribution Systems, *K. R. D. Wolfe.*
The Prevention of External Pipe Corrosion Thru the Use of Expendable Anodes, *W. E. Huddleston.*
What's New In Heating, *Carl H. Dean.*

Pacific Chemical Exposition—Industrial Conferences

San Francisco, California, October 21-25, 1947

Aromatic Hydrocarbons From Petroleum, *G. L. Parkhurst.*
An Automatic Laboratory Batch Distillation Column With Automatic Reflux Ratio Advance, *L. S. Galstaun, L. A. Bisso, R. D. Harrison, and E. R. Keever.*
Applications of the Fluidized Solids Technique, *E. V. Murphree, E. J. Gohr, and A. F. Kaulakis.*
Chemistry and Engineering in the Oil Industry, *Gustav Egloff.*
Investigation of Deposition and Oil Deterioration Phenomena by Means of a Motored Engine, *H. Dimond, H. C. Kennedy, and R. G. Larsen.*
Process for Manufacture of Gasoline by Polymerizing Propene and Butene, *L. F. Brooke.*
Selenium Containing Lubricant Additives, *Frank C. Croxton.*
The Influence of Fuel Votality on the Fire Hazard in Aircraft, *A. G. Cattaneo, F. G. Bollo, and E. S. Starkman.*
The Utilization of Dihydrophthalic Acid in Alkyd Resins, *F. G. Lum and L. H. Brown.*

Petroleum Electric Power Association

Annual Meeting
Corpus Christi, Texas, November 20-21, 1947

Advertising 1948, *Ray T. Glenn and T. A. Workman.*
Pree Pumping System, *H. K. Ihrig.*
Growth of Power Demands—South Texas, *Geo. A. Mills.*
Message from Petroleum Industry Electrical Association, *J. F. Collerain.*
Modern Pipe Line Electrification, *D. H. Levy.*
Operation of Tennessee Gas Transmission Company (Pine Lines), *G. R. Rice.*
This Production Business, *John G. Calvert.*
This Is Your Petroleum Electric Power Association—History of and Objectives, *A. R. (Lon) Watson.*

Petroleum Industry Electrical Association

Annual Meeting
Dallas, Texas, June 1-2-3, 1948

Electric Power Generation With Gas Turbines, *Cecil Jordan.*
Frequency Allocations and Radio Station Classification for the Petroleum Industry, *Jos. H. Wofford.*
Hydrocarbons in Industry, *G. R. Walton.*
Report on API Committee on Radio, *F. W. Littell.*
Some New Equipment for the Petroleum Industry, *T. R. Rhea.*

Porcelain Enamel Institute

Annual Forum, Ohio State University
Columbus, Ohio, September 10-12, 1947

Bright Annealing, *A. R. Mallon.*
Conventional Pickle Practice, *A. M. Langbein.*
Demonstration and Discussion of Apparatus for Evaluation of Adherence, *A. C. Francisco.*
Fuel Oils, *William Jones.*
How to Choose the Correct Type of Porcelain Enamel for Specific Applications, *J. E. Hansen.*
Immersion Heating Application, *S. E. Shepard.*
Importance of Selection of Proper Personnel, *Dr. Perry L. Rohrer.*
Job Evaluation and Wage Incentives, *J. M. Schappert.*
Production Planning, *E. H. Smedley.*
Pyrometry and Its Application in Porcelain Enameling Plants, *John Green.*
Spray Cleaning and Pickling, *George Tuttle.*
Spray Pickling, *H. C. Ellinger.*
Use of Liquified Petroleum Gas, *E. A. Jamison.*

Secondary Recovery Conference

Pennsylvania State College
October 31-November 1, 1947

Effect of Water Injection in Gas Drive, *D. E. Menzie.*
Relative Permeability Studies, *J. H. Henderson and S. T. Yuster.*
Report on Selective Plugging With Smoke, *R. F. Neilsen.*
Water Flood Spacing, *S. T. Yuster.*

Secondary Recovery Forum

Washington, D. C., May 15-16, 1947

Economic Research — Statement presented by Brundred Oil Corporation, Oil City, Pa., *Robert B. Bossler.*
Investigations on Secondary Recovery by the Illinois State Geological Survey, *Alfred H. Bell.*
Planning and Placing Into Operation Secondary Recovery Programs, *L. B. Elkins.*
Promulgating Secondary Recovery Information, *G. Gerald Bauer.*
Research Developments in the Pennsylvania Grade Region, *J. Paul Jones.*
Secondary Recovery Committee of the North Texas Oil and Gas Association, *Presented by Fred Sehmann, Secretary.*
Secondary Recovery Operations of Magnolia Petroleum Company, *Presented by Fred Wright, Jr.*
Secondary Recovery Research at the Pennsylvania State College, *Dr. S. T. Yuster.*
Statement of Activities of the Secondary Recovery Production Research Group of the Pennsylvania Grade Crude Oil Association, *Richard V. Hughes.*
Statement of Carl Young, Director, Division of Production, API.
Statement of Don T. Andrus, Bradford, Pa.
Statement of Secondary Recovery Committee of the Independent Petroleum Association of America.

Statement on the South Burbank Pool—Osage County, Oklahoma—for the Secondary Recovery Forum, *C. P. Dimit.*
Statement on Secondary Recovery of Oil in West Virginia, *J. E. Billingsley.*
U. S. Bureau of Mines, *C. C. Anderson.*
West Virginia Geological Survey's Work Related to Secondary Recovery, *Paul H. Price.*
Statement of the Interstate Oil Compact Commission, *Hiram M. Dow.*
Statement of Paul D. Torrey, Chairman, API tanding Subcommittee on Secondary Recovery Methods.
Statement of Secondary Recovery Committee of the North Texas Oil and Gas Association.

Society of Automotive Engineers

Annual Meeting
Detroit, Michigan, January 12-16, 1948

Diesel Engine Exhaust Smoke Is Influenced by Fuel Characteristics, *H. D. Young.*
Engine Wear Research, *L. D. Thompson, S. J. Backey, and E. L. Conn.*
Effect of Engine Operating Conditions on Oil Contamination and Sludge Formation, *Carl W. Georgi.*
Full Scale Engine Performance Characteristics of Aviation Safety Type Fuels, *W. J. Sweeney, J. F. Kunc, Jr., W. C. Howell, Jr., and O. G. Lewis.*
Preliminary Report of Studies on the Composition and Physical Properties of Diesel Fuels, *Harold M. Smith.*
Technique of Exhaust Smoke Measurement, *Jordan P. Jung and Frank L. Coers.*
U. S. Naval Engineering Experiment Station Investigations on Cylinder Liner Wear, *Warren G. Payne and William F. Joachim.*

National West Coast Transportation and Maintenance Meeting
Los Angeles, California, August 21-22, 1947

Brake Troubles—Increase With Power Application.
Fleet Operation Is Important Business, *Frederick C. Horner.*
Lubrication—Its Effect on Reducing Mechanical Wear, *W. M. Sopher.*
Regulations, Their Effect on Transportation Management, *E. O. Sawyer, Jr.*
Selection and Application of Trailer Equipment, *V. M. Drew.*
Shotpeening, *Fred K. Landecker.*
The Selection and Application of Trucks, *J. Alvin Bauman.*

Southern Gas Association

Short Course in Gas Technology
College of Arts and Industries
Kingsville, Texas, June 2-4, 1948

Automotive and Remote Control of Gas Pipe Line Flow, *W. M. Moore.*
Centrifugal Compressors at the Seeligson Plant, *Dan T. McDonald.*
Characteristics of Large Size Gas Air Conditioning Equipment, *Walter F. Friend.*
Selection of Air Conditioning Equipment, *Walter F. Friend.*
Chemurgic Processes Using Natural Gas As a Fuel, *Victor H. Schoffelmeyer.*
Design Problems in the Selection of Burners for Industrial Applications, *L. S. Reagan.*
Developments in the Construction of Large Diameter Pipe Lines, *L. H. Favrot.*
Deviation: An Essential Factor in Balancing Volumes in High Pressure Production and Transmission of Natural Gas, *E. N. Armstrong.*
Drying of Lumber With Natural Gas, *Mark M. Lebrbas.*
Gas-Engine Powered Compressors for Refrigeration and Air Conditioning, *M. F. Whitney.*
Improvements in Air Distribution System Design, *H. Charles Pierce.*
Latest Developments in Corrosion Prevention, *Starr Thayer and Robert Kuhn.*
Latest Developments in Types, Applications and Testing of Pipe Coatings, *Stephen D. Day.*
The Design of Centrifugal Compressors for Natural Gas Transmission, *by a Representative of Ingersoll-Rand.*
Trends in Natural Gas Cycling Operations, *Dr. E. O. Bennett.*

Texas Mid-Continent Oil and Gas Association

Annual Meeting
San Antonio, Texas, October 16-17, 1947

Hidden Oil, *Ernest O. Thompson.*
Oil's Stewardship, *Robert G. Dunlop.*
Operations Washington, *Frank M. Porter.*
President's Address, *Fred W. Shield.*
Report of the Theft Prevention Committee, *P. W. Pitzer, Jr.*
Some Competitive Aspects of the Manufacture of Chemicals From Petroleum, *W. P. Gage.*
The Current and Future Supply of Oil Country Tubular Goods, *A. E. Walker.*
The Effect of the Tidelands Decision, *Governor Millard F. Caldwell.*
The Production Job of the Oil Industry, *S. A. Swensrud.*

Western Petroleum Refiners Association

Wichita, Kansas, June 11, 1948

Combustion and Efficiency, *Hugh Wiant.*
Fundamental Principles of Design of Suspended Arches and Sectionally Supported Walls, *George Ellerton, Jr.*

Technical and Industrial Relations Meeting
Shreveport, Louisiana, January 23, 1948

Koch Kaskade Fractionating Tray, *H. Litkin.*
Management—Foreman to President, *W. W. Finlay.*

Annual Meeting
Galveston, Texas, April 5-7, 1948

Appraisal of Gas Synthesis Operations, *R. C. Alden and A. Clark.*
Application of the Fluid Catalyst Technique of Catalytic Cracking and Hydrocarbon Synthesis, *Dr. R. W. Krebs.*
Improving Engine Lubricating Oils Through the Use of Additives, *C. J. Livingstone and W. A. Howe.*
Motor Gasoline Refining and Utilization, *W. M. Holaday.*
National Petroleum Council—Its Purposes and Functions, *Walter S. Hallanan.*
Oil Shale As a ource of Synthetic Liquid Fuels, *Boyd Guthrie and John G. Tripp.*

Western Society of Engineers

Storage of Natural Gas in Underground Pipe Sections, *D. V. Meiller.*

World Power Conference

The Hague, Holland, September 2-9, 1947

Additional Sources of Output Given by Gas Turbine (Switzerland), *W. Karrer.*
Adoption of Modern Techniques by the French Petroleum Refining Industry (France), *R. Perrin.*
Advances in Motor Fuel Manufacturing Processes Leading to Better Fuel Economy (U. S.), *A. J. Blackwood, E. V. Murphree and A. C. Patterson.*
Atomic Energy in France, *M. Kowarski.*
Aviation Fuel Production (England), *Major K. Gordon and J. A. Oriel.*
Boilers for Special Fuels (U. S.), *O. deLorenzi.*
Carbohydrates and Related Constituents of Plant Tissues as a Supplement to Coal and Petroleum, *E. L. Ritman.*
Coal and Oil Compared for Various Purposes (Netherlands), *W. B. Asscher.*
Nuclear Energy for Power Production (U. S.).
Comparison of Different Sources of Energy for Railways (France), *M. Dugas.*
Dark Fuels: Boiler, Diesel and Gas Turbine, *J. J. Broeze.*
Dependence of Gas Turbine Economy on Internal Aerodynamic Design (England), *H. Roxbee Cox.*
Early Expected Uses of the Gas Turbine in France, *Professor Roy.*
Electronic Combustion Control of Steam Boilers (Czechoslovakia), *Z. V. Ryska.*
Energy Utilization in Marine Transportation (France), *M. Thery.*
High-Frequency Application in Work Shops and Steel Mills (Sweden).
High Temperature Recuperators and Their Application (Australia), *H. Escher.*
Hot-Air Engines (Netherlands), *H. Rinia.*
Long-Distance Distribution of Gas (Czechoslovakia), *Dr. Riedl.*
Natural Gas Reserves In the United States, *the Committee on Natural Gas Reserves of the American Gas Association.*
New Ways of Burning Liquid Fuel, *H. J. K. v.d. Bussche and W. L. v.d. Putte.*
Possible Interchange on Future Large Interconnections (France), *P. Ailleret.*
Production of Shale Oil in Sweden, *E. Schianberg.*
Shale Oil Production In Sweden With Particular Reference to Direct Production From the Shale Deposits in Situ.
Technical Comments on Fuel Economy In Switzerland During the War, *Professor Schlaepfer.*
The Application of Nuclear Energy to the Generation of Heat and Power, *J. D. Cockcroft.*
The Bituminous Sands of Alberta, Canada, As a Source of Liquid Fuel, *K. W. Bowles and T. E. Warren.*
The Development of Several Techniques of Synthesis and Substitution—Energy Considerations (France), *Guesdon and Jacque.*
The Domestic Transport of Petroleum (France), *M. Rouelle.*
The Production of Energy In France, and Utilization of Sources of Energy In France From 1939 to 1946, *Pierre Salmon.*
The Functions of Convection and Radiation In Heating By Gas (England), *L. W. Andrew and A. L. Roberts.*
Thermal Economy In Swiss Gasworks and Coke Plants: Dry Cooling of Coke: Heat Economy In Obtaining Benzol, *Deringer and Herrsche.*
Transmission of Gas In France, *Fleurquin and Malherbe.*

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ADVERTISERS *index*

A

American Chain & Cable Co., Inc. 174
American Iron & Machine Works Co. Back Cover
American Manufacturing Co. of Texas 2
American Roller Bearing Co. 134
Armstrong Bros. Tool Co. 210
Axelson Manufacturing Co. Inside Back Cover

B

Baash-Ross Tool Co. 145
Babcock & Wilcox Tube Co. 71
Baker Oil Tools, Inc. 208
Bantam Bearings Div., Torrington Co. 200
Baroid Sales Division, National Lead Co. 87
Baroid Sales Div., Specialties Dept., National Lead Co. 212
Bethlehem Supply Co. 5
Brown Instrument Co., The 127
Brown & Root, Inc. 13
Burgess-Manning Co. 221
Butane Equipment Co., Inc. 166

C

Cameron Iron Works, Inc. 30
Campbell, J. A., Co. 210
Chapman Valve Mfg. Co. 79
Chicago Bridge & Iron Co. Inside Front Cover
Classified Advertisements 206
Continental Supply Co. 210
Cook, C. Lee, Manufacturing Co. 21
Cooper-Bessemer Corp. 55
Core Laboratories, Inc. 178
Crane Co. 40
Cummins Engine Co. 114

D

Darling Valve & Manufacturing Co. 211
Dean Bros. Pumps, Inc. 215
Detroit Diesel Engine Div., General Motors Corp. 97
Dow Chemical Co., The 167
Dowell, Incorporated 19
Dresser Industries, Inc. 11,125,135,180
Dresser Manufacturing Div. 135
Drilling Specialties Co. 117
Dura metallic Corp. 218

E

Emsco Derrick & Equipment Co. 93
Engineering Laboratories, Inc. 101

F

Fawick Airflex Co., Inc. 38
Fluor Corporation, Ltd. 33
Ford Motor Co. 75
Foxboro Co., The 123

G

Gaso Pump & Burner Mfg. Co. 132
General American Transportation Corp., Plate & Welding Division 169
General American Transportation Corp., Wiggins Seal Division 105
General Electric Co. 7
General Paint Corp. 203
Graver Construction Co. 4
Graver Tank & Mfg. Co., Inc. 202
Gray Tool Co. 139,192
Griscom-Russell Co. 194
Grove Regulator Co. 181
Gulberson Corp. 34
Gulf Oil Corp. 24

H

Haering, D. W., & Co. 172
Halliburton Oil Well Cementing Company Front Cover
Harrisburg Steel Corp. 184
Helicoid Gage Div., American Chain & Cable Co., Inc. 174
Hercules Tool Co. 138
Hill, Hubbell & Co. Div., General Paint Corp. 203
Hobbs Manufacturing Co. 176
Hughes Tool Co. 69
Hyatt Bearings Div., General Motors Corp 190

I

Ingersoll-Rand Co. 35
International Harvester Co. 42
International Rolling Mill Products Corp. 111,112

J

Jensen Bros. Mfg. Co. 204
Johnston, M. O., Oil Field Service Corp. 3
Jones, S. M., Co., The 103

K

Kellogg, M. W., Co. 73
Kobe, Inc. 11

L

Lane-Wells Co. 66,67,99,121,209
Larkin Packer Co. 39
Layne & Bowler, Inc. 154
Lenkurt Electric Co. 220
LeRoi Co. 185
Linde Air Products Co. 159
Line Scale Co., Inc. 214
Link-Belt Co. 91
Lufkin Foundry & Machine Co. 63
Lunkenheimer Co., The 168

M

McCullough Tool Co. 183
McNamar Boiler & Tank Co. 198
Magnet Cove Barium Corp. 27
Maintenance Engineering Corp. 28
Mark, Clayton, & Co. 207
Marsh, Jas. P., Corp. 32
Means Laboratories, Inc. 210
Mercoid Corp. 128
Mission Manufacturing Co. 89

N

National Radiator Co., Industrial Div. 29
National Supply Co. 57,60
National Technical Laboratories 6
National Tube Co. 157
Nikoh Tube Co. 111,112
Nordstrom Valve Div. 129,130
Norris, W. C., Manufacturer, Inc. 1
Oakite Products, Inc. 221

O

Oil Base, Inc. 94
Oil Well Supply Co. 155
Onan, D. W., & Sons, Inc. 214
Otis Pressure Control, Inc. 149

P

Pacific Pumps, Inc. 180
Patterson-Ballagh Div. of Byron Jackson Co. 77,211
Peerless Pump Div., Food Machinery Corp 76
Penberthy Injector Co. 17
Petroleum Electric Power Association 160
Petroleum Rectifying Co. 165
Phoenix Mfg. Co. 221
Pittsburgh Equitable Meter Div. 26
Pritchard, J. F., & Co. 175

R

Rector Well Equipment Co., Inc. 173
Reed Roller Bit Co. 66
Refinery Supply Co., The 213
Republic Steel Corp. 137,196
Republic Supply Co. 142-143
Ric-wiL Co., The 81
Ridge Tool Co. 216,217
Rockford Clutch Div. 220

S

SKF Industries, Inc. 151
Schlumberger Surenco 147
Shaffer Tool Works 140
Smith, A. O., Corp. 85,119
Spang & Co. 118
Spang-Chalfant Div., The National Supply Co. 58-59
Standard Oil Co. of California 36
Standard Oil Co. of New Jersey 162,163
Sun Shipbuilding & Dry Dock Co. 20

T

Taylor, S. G., Chain Co. 206
Technical Oil Tool Corp., Ltd. 37
Tempil° Corp. 204
Templeton-Kenly & Co. 211
Thermoid Co. 177
Thompson Tool Co. 120
Torrington Co., Bantam Bearings Div. 200
Tretolite Co. 31
Twin Disc Clutch Co. 83

U

Union Carbide & Carbon Corp. 159
United States Steel Corp. 155,157
Universal Oil Products 23

V

Visco Products Co., Inc. 170

W

W-K-M Co., Inc. 109
Watson-Stillman Co. 107
Waukesha Motor Co. 9
Wedge Protectors, Inc. 158
Whitney Chain & Mfg. Co., The 65
Wickes Boiler Co., The 188
Wilson Manufacturing Co. 153
Wilson Supply Co. 186
Wisconsin Motor Corp. 154
Worthington Pump & Machinery Corp. 41

Y

Young Radiator Co. 219
Youngstown Sheet & Tube Co. 25